EVALUATION OF VEHICLE PERFORMANCE IN COAST GUARD SEARCH AND RESCUE MISSIONS

Donnie David Polk

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

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IN COAST GUARD SEARCH AND RESCUE MISSIONS

by

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and

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Evaluation of Vehicle Performance
in Coast Guard Search and Rescue Missions

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TABLE OF CONTENTS

I. INTRODUCTION

Title 14 of the United States Code establishes that the primary responsibility of the Coast Guard is to maintain and operate rescue facilities for the promotion of safety on, under, and over the high seas and waters subject to the jurisdiction of the United States. The waters subject to U.S. jurisdiction include territorial waters (approximately 3 miles to sea from the continental coast line), inland rivers and waterways, and the Great Lakes. This responsibility directly translates into the mission called SAR (search and rescue) which is defined to be the employment of personnel and facilities in rendering aid to persons and property in distress. Although SAR is the primary mission, the Coast Guard is tasked with other mission duties involving law enforcement, marine environmental protection, port security, ice breaking, and maintaining aids to navigation in the applicable maritime regions.

The Coast Guard utilizes numerous types of surface and airborne craft in the fulfillment of its mission responsibilities. Resources and supporting manpower are allocated to stations strategically located throughout the United States. The allocation scheme is primarily dictated by the geography and workload of the district. Consequently, there is no such thing as a standard Coast Guard station in the

total organization. The size and number of resources for each station differ, but invariably each resource is required to have some multi-mission capability. To have one type of craft fully capable of performing every mission task effectively is a tall order simply because of the vast scope of operational demands. But to have a minimal variety of versatile craft performing the missions effectively is a realistic goal which would accrue obvious benefits in maintenance, training, and personnel adaptability requirements. To this end it would be extremely valuable to have some sort of model which could be exercised to evaluate tentative replacement craft in the overall performance of multi-mission tasks. Such a model would identify good candidates for procurement, would minimize the costly operational testing and evaluation required for proposed craft, and might preclude the need for testing of inferior craft. Ultimately the results of this model may aid in the choice of an optimal mix of resources to perform all Coast Guard missions.

A decision methodology and proposed model were developed in an effort to achieve this objective. A sensitivity analysis was conducted to reveal strong points and weaknesses of the model and recommendations were set forth for possible extension of the model. Results were evaluated and conclusions made concerning the feasibility of using the model.

II. NATURE OF THE PROBLEM

The Coast Guard operates and maintains a wide variety of craft, ranging from 17-foot utility boats to 378-foot High Endurance Cutters, long-range C-130 aircraft, amphibious aircraft, and helicopters. These resources are integral to the performance of Coast Guard missions in the maritime environment. A large portion of the current inventory of resources have reached a state of near-antiquity. Practically all of the ninety-five foot coastal patrol boats (designated WPB 95) have reached their service life expectancy of 20 years. The HH-52A Sikorsky helicopter has a service life of 15 years and by 1980 a majority of these aircraft will require either modification or retirement. This "old age" problem has not caught Coast Guard planners totally by surprise, however. The introduction of the larger and longer range HH3-F helicopter serves to share the workload of the HH-52A (Sea Guard) and also provides a mid-range capability not afforded by the smaller helicopter. This augmented capability allows a potential for expanded Coast Guard involvement in other areas not realized by the Sea Guard.

The eighty-two foot patrol boat (WPB 82) has been procured to eventually replace the WPB 95 and to keep pace with inflating mission demands. The WPB 82 performance characteristics are nearly identical to the WPB 95 but this one to one replacement principle does not really lend itself to progressive acceptance of expanding duties.

The problem concerns not only replacement of older resources to provide the current level of readiness and effectiveness in all missions, but also involves augmentation of the total current inventory to insure that today's effectiveness standards can be maintained in the face of increased responsibilities. Coast Guard activity can be expected to expand with the establishment of deep-water ports and the likely extension of the twelve mile fisheries zone into a two-hundred mile band. Additionally, increased emphasis on oil spill prevention and cleanup involves a magnification of effort in the areas of Marine Environmental Protection (MEP) and Port Safety and Security (PSS). The recreational boating populace is swelling at a rate of six per cent per year and the total number of search and rescue cases annually has shown the same trend. Studies have indicated that the Coast Guard is actively involved in only about 13% of all recreational boating rescue and/or assistance situations primarily due to the lack of a communications link between the imperiled boater and the nearest Coast Guard rescue station. This thirteen per cent figure may balloon quickly if automatic alerting devices, such as DALS (Distress Alerting and Locating System) become mandatory equipment for recreational boats. In the face of burgeoning responsibilities in practically all areas, the Coast Guard's operating inventory is becoming insufficient to meet the increased demands.

Under the constant pressure of tight budgets, the Coast Guard has had to take a hard look at its operational requirements. For example, what is the true value of speed in fulfillment of missions? Are there craft which can provide the same level of effectiveness yet require fewer manning personnel? (The WPB 82 and the WPB 95 have comparable capabilities but the former operates with five less crewmen.) How important is a search capability? How about the ability to tow a disabled vessel?

With the exceptions of icebreaking and aids to navigation operations which require specially configured and equipped vessels, it is difficult to justify the procurement of a surface or aviation craft that is limited to utilization for only one mission. This implied multi-mission capability requirement severely limits the choices of suitable craft to be considered. While it may be unrealistic to expect that some new type of surface vehicle or aircraft can perform exceptionally in all areas of Coast Guard oriented tasks, it may be possible to identify the resource that performs best throughout the entire range of mission demands. To know how each candidate craft performs in specific mission tasks as well as under a multi-mission concept then becomes valuable information to a decision maker. Some analytic framework is needed which will enable the Coast Guard to evaluate the performance of proposed replacement craft under both the single and multi-mission concept of operations. Such a general framework might be constructed in the following manner.

Initially all Coast Guard missions are divided into separate phases distinguished by the type of tasks to be performed in executing that particular mission. Key words would identify the tasks peculiar to each phase. For example, if all Coast Guard activity centered on the three missions of Marine Environmental Protection (MEP), Enforcement of Laws and Treaties (ELT) and Search and Rescue (SAR), the following phase breakdown of tasks may apply:

MISSION	PHASE I RESPONSE	PHASE II TRANSIT	PHASE III EMPLOYMENT
MEP	Onload pollution equipment	passage	containment, cleanup and investigation
ELT	standby on station	patrol and interdict	enforcement
SAR	alert unit readied	transit	assistance to disabled vessel

As it now stands, each mission has its own unique and specific phase description. The task descriptions under phase I include a form of preparation and could be grouped under a phase heading "response". Likewise, phase II could be classified as "transit". The third phase tasks include the operations involved upon arrival to the scene of action and might be categorized as "employment". The aggregation of the individual task descriptions into generalized phase classifications would serve the purpose of identifying task functions common to all missions. These common functions

would then become the basis for determining what craft capabilities are desirable in each phase. By specifying these phases carefully and selecting a resource that performs effectively in each, the adaptability of that resource to multiple mission tasks would be reasonably assured. This approach prevents the possible selection of a craft which can do one mission extremely well but cannot perform another equally important one.

Once the general phases are identified, the next step would be to develop a technique for evaluating any proposed craft in the performance of the separate phases. Assuming each phase is equally important to the outcome, a total performance measure could be obtained by adding the craft performance values for each phase. If phases are unequal in importance, the same reasoning applies but the individual performance values could be weighted accordingly.

These phase performance values could be determined by developing relationships for known craft characteristics. Extending the previous example, transit may be assumed to be a function of 1) resource speed in typical sea states, 2) survivability in specific environmental conditions, 3) vertical acceleration of the craft that leads to crew discomfort and sea-sickness, 4) sail area and draft affecting set and drift in certain wind conditions and ocean currents, etc. Once a relationship for each phase has been derived, the sources being considered and their "scores" for each phase

can be displayed in matrix form for further manipulations. These derived performance values have significance when viewed in a comparative context. For instance, Craft A may have a score of 5 and Craft B a value of 4 on a scale of 0 to 10. The primary inference to be made is that Craft A is preferred to Craft B, according to performance criteria. The total matrix display would provide comparative craft performance information which could facilitate selection of a resource for testing or procurement.

The purpose of this work will be to illustrate the general methodology by concentrating on only one mission, Search and Rescue. Although all of the following analytical discussion applies solely to SAR, the principles are adaptable to the combination of many missions mentioned previously. By starting with a single mission concept, attention can be directed to the procedural steps without getting bogged down with lengthy enumeration and phase aggregation of mission tasks. However, the phraseology will be as general as possible to suggest natural extensions along the multi-mission concepts. It should be kept in mind that in demonstrating the workability of this model, there may be occasions to criticize numerical entries arising from subjective evaluation of some factors where operational or test data was not available. Naturally, some real questions on how a craft's performance can be evaluated are raised. The answers are difficult to come by! While the potential for this type of censure is acknowledged,

the point to remember is that it is the methodology that is of concern, not the accuracy of the authors' subjective views.

There are various reasons for choosing to analyze the SAR mission in preference to the others. Primarily, it was chosen because of the abundance of operational data available. Subsequent to the termination of every SAR incident, an assistance report, CG-3272 (Appendix A) is forwarded, via the chain of command, from the assisting resource to Coast Guard headquarters. These reports are compiled and stored on magnetic data tapes for each fiscal year. The three most recent years (FY71 through FY73) were used to gather statistics.

Secondarily, SAR was selected because of the authors' experience in this field. A combined total of ten years of Coast Guard service has been devoted to Search and Rescue work. The operational experience includes four years of flying amphibious rescue craft, four years aboard high endurance cutters, and two years as Commanding Officer of a WPB 95. In addition, two days temporary duty aboard the hydrofoil Flagstaff provided first-hand knowledge about a new type of craft. Nearly every type of SAR task has been experienced by the authors in this ten year period, both on the East and West Coasts.

By restricting the scope of the study to one mission it may appear that the importance heretofore placed on multi-mission capability is ignored. However, as will be shown

later, the SAR mission will be broken down into separate categories of SAR activity. Not all resources can perform all the tasks that make up the SAR mission, and, likewise, resources differ in the effectiveness with which they complete the tasks that they can perform. Consequently, analysis of the wide variety of SAR activity has basically the same effect as combining many missions and analyzing them. This will become clear in the specific applications in the following chapter.

In summary, the problem of procurring suitable replacements for aging resources, and the selection of new craft to meet the expanding responsibilities of the future must be satisfactorily resolved. An evaluation methodology to determine the capabilities of proposed replacement craft in Coast Guard missions would assist decision makers invaluably in this regard. This work is a first attempt at producing such a model using only the SAR mission. A future step would be to combine those individual craft capabilities into a model for evaluating a mix of craft at a particular station.

III. METHODOLOGY

Eight resources were selected for evaluation in their performance of the SAR mission. Four were high performance craft representative of hydrofoils, surface effect ships, and air cushion vehicles, all of which offer the special advantage of high operating speeds. Three were conventional-hull vessels currently handling a large proportion of SAR duty. The type of duties performed by these conventional craft generally describes the expected range of operations for the size of high performance craft considered in the analysis and furthermore these craft provide a low-speed reference for comparison in evaluating the high performance craft. One helicopter type was included to provide the model with a high-speed craft currently used in SAR for upper bound comparison. All of the vehicles are medium-range craft having the capacity to facilitate assistance out to 150 miles offshore. The aim was to compare the ability of these craft to perform a given workload within this general range of operations. In determining a measure of effectiveness for any resource, three aspects were considered.

1. Phase breakdown of the mission (distinguished by type of tasks to be completed) and performance in each phase.
2. The importance of each phase as determined by the percentage of total time spent in each.
3. The actual workload for a designated period of time.

Each particular rescue operation was broken down into four separate phases. These are response (R), transit (T), search (S), and assistance (A). The craft's effectiveness in each phase was calculated and indicated by a scale column vector (ϕ_α) consisting of four elements.

Next, the average time recorded in each phase was obtained from historical SAR data and divided into nine separate SAR categories to form the reference base (three years of cases involving WPBs). The individual times were divided by the total time on the case converting the times into proportions. This yielded a (9 X 4) matrix referred to as the time weighting matrix ($\%_{k\alpha}$). The base times for the WPB were adjusted as appropriate for variables such as transit speed and response time to produce a unique time-weighting matrix for each craft.

The fourth phase consists of the actual assistance rendered to the disabled vessel. Obviously if a particular craft is incapable of providing the type of assistance required, the scale value for this assistance phase is zero. This implies that the completion of the three prior phases of response, transit and search, should in retrospect, be considered valueless also. To account for this, an adjustment was made in the computations for total craft performance. A dummy variable was introduced whose value depends upon whether the craft under consideration could successfully complete the mission. The value of the dummy variable is

unity unless the resource has a zero in its scale vector for a particular assistance sub-category. In the latter case the dummy variable takes on the value zero.

A total performance matrix, (P_{kj}), was then constructed in the following manner. For every craft evaluated ($j = 1,.....,8$) a performance vector was computed by multiplying the $(\%_{k\alpha})$ matrix corresponding to that craft by the scale vector corresponding to that resource and by the scalar dummy variable representing the "probability" that the craft could complete the k^{th} type of SAR mission. This resulted in eight (9 X 1) performance vectors. These vectors were combined to form the (9 X 8) performance matrix (P_{kj}) representing the performance of the j^{th} craft in the k^{th} SAR category. For clarification of the multiplication procedure see Appendix C.

If all nine assistance categories occurred in equal proportions, the performance matrix would be the final step in the development of the model. However, this is hardly the case. Because of the non-uniform distribution of SAR categories, the performance matrix does not reflect the true worth of a craft to the Coast Guard. This is rectified by establishing a workload matrix based on historical data (FY71 through FY73) which indicates the frequency of occurrences of the nine assistance categories with respect to distances offshore and case severity codes. The performance matrix was pre-multiplied by the workload matrix to produce a

measure of effectiveness matrix which indicates the overall performance values for a resource in doing the Coast Guard mission.

The development and construction of each matrix is discussed in detail in the following sections. The analytical model described in section D combines all of the matrices into the final measure of effectiveness matrix. The computations involved to produce the measure of effectiveness matrix with interpretations and implications of the individual elements are included in the final section of this chapter.

A. SCALE MATRIX FORMULATION

The performance of a search and rescue (SAR) vehicle can be evaluated by measuring how well it can complete the four phases of every mission operation. Chronologically these are response, transit, search, and on-scene rendering of assistance. The relative significance of each phase may be visualized by examining the chain of actions resulting from the generation of a hypothetical search and rescue incident. A maritime distress call is received at a Rescue Coordination Center (RCC). This initial notification to the Coast Guard could have been received in a variety of ways. An SOS signal may have been intercepted by a recreational boater who relayed the information to the nearest communication facility or a fishing vessel may have been reported overdue by a telephone

call. Regardless of how the call for help is received, the following sequence of actions result in response to the distress.

RCC alerts the appropriate rescue facility via direct communication hot lines and the assisting resource is prepared to get underway. The only delay incurred here is for decision analysis – what is the proper resource to send? The RCC controller has at his disposal a current display board listing all available resources which can be utilized to prosecute a mission. The type of resource the controller dispatches is dependent upon the nature and severity of the situation, the location of the nearest search and rescue unit (SRU), and the weather conditions. Except for cases classified as "involving small danger to persons and property", the resource which can arrive on scene the earliest is usually detailed to handle the case. Once the desired resource is determined, the appropriate operating facility is notified.

Total mission time is assumed to commence upon notification of the assisting operating facility. Time is an extremely critical factor in severe cases, but is less significant in rescue situations classified as moderate or light. But the true nature of the distress is an after the fact determination and because of this initial uncertainty, the relative importance of response has to be highlighted. Response time used herein shall be defined to be the time from assisting facility notification until the first search and rescue unit

(SRU) gets underway. The second phase, transit time, is self-explanatory and runs from unit time underway until arrival on scene of the reported incident. If the location of the distressed unit is positively defined, the next phase of operations is eliminated. However, as verified by historical data, a significant part of the total time required to prosecute a case is spent in the search mode. Search time duration is the difference between first arrival on scene of the reported incident until location of the distressed unit or termination due to fuel requirements or completion of assigned search pattern, etc. Search time in the latter cases ends when the SRU departs scene enroute to its home facility or temporary base of operations. The SEARCH AND RESCUE REPORTS MANUAL, (CG-397), distinguishes the nature of assistance rendered by the classifications of personnel and property. These are sub-divided into numerous specific types of assistance such as medical evacuation of personnel, dewatering of flooded boats, or towing of disabled boats. Each type places a certain demand requirement on the assisting SRU. As delineated in the workload matrix, there are nine general types of operations involved which necessitate different attributes of the assisting resource. This final phase of operations (assistance time), obviously must be performed or the entire mission fails.

A resource's performance in a particular mission can be estimated using time as a proxy measure for how well it does.

The cumulative time in the four individual phases represents the total measure of performance and indicates the relative effectiveness of that craft. The minimum cumulative time would be associated with the most effective craft.

The Coast Guard records the operating facility "time of notification" and "unit time underway" for each particular incident on Form CG-3272 (Assistance Report). A simple subtraction of the two times, averaged over all cases for the three year period (FY-71 through FY-73) resulted in an average response time for the rescue units being utilized. For the purpose of this work the primary interest lay in the response times of the WPB's, the helicopters, and the medium endurance cutters. A number of variables affect the total response time. The number of personnel required to man the resource, the equipment to be onloaded, the mandatory machinery warmup time, and even the time of occurrence of the distress influence the response time duration. Crew reaction during the early hours of morning is bound to be slower than at peak hours of the afternoon, for example. Response time data on new craft is limited to test and evaluation studies at best and doesn't reflect the same degree of accuracy afforded by years of operational data on Coast Guard units. However, the accuracy of these estimates is sufficient for the purposes intended.

A test of the FLAGSTAFF's suitability in Coast Guard missions was conducted in November 1974. The FLAGSTAFF and

a WPB (Point Bower) were both assigned SAR duty and operated from the same facility. In the few recorded cases the FLAGSTAFF trailed the Point Bower in getting underway by approximately five minutes. Similar response time is predicted for other hydrofoils under evaluation.

A Coast Guard evaluation of the SK-5 Air Cushion Vehicle was completed in October 1971 [Ref. 2]. The average response time in this study was reported to compare favorably with that of the helicopter. The ACV response time determined by CNA [Ref. 3] in a study for the Coast Guard exceeded the earlier study reported by five minutes. To prevent overstating a craft's response capability, the larger number is used in later calculations. The Surface Effect Ship (SES), is the only proposed craft of this work which has not been evaluated in SAR missions. Because of the similarity to the ACV, the response time will be estimated to be the same as for the ACV.

The average response times for the current Coast Guard units were extracted directly from the data except for the WMEC-210 and the HH-52A for reasons specified in section B. The helicopter response time was estimated from experience while serving at Air Station Miami. The time of launch notification and actual liftoff time are recorded for each case involving the HH-52A in an operation duty officer's log. A simple calculation yielded the response time averaged over numerous cases. Air Station Miami is assumed to be a typical

air unit. The response time for the medium endurance cutter was taken from Coast Guard estimates used as input to the Search and Rescue Simulation model (SARSIM).

Existing operating facilities have a sufficient number of units to provide a ready craft when needed, so this does not influence the response time data. If this assumption were not permissible, then the probability of a unit being operationally available when called upon could be calculated and the average response time adjusted accordingly. The following table summarizes the response times for each of the proposed craft:

Resource	Response Time (minutes)	Scale Value
Flagstaff	25	4.0
Highpoint	25	4.0
Voyageur	15	6.7
HH-52A	10	10.0
Hoverferry	15	6.7
WPB 82'	20	5.0
WPB 95'	20	5.0
WMEC 210'	60	1.7

A method is needed to convert raw performance numbers into values which depict the relative advantage of each craft and have the quality of being dimensionless. The conversion to scale values must be consistent for each phase, or an undue bias might be introduced since each value represents

time values which should be consistently additive. To properly reflect equal phase importance the mean value of each phase should be approximately the same. The deviation from the mean will reflect the variability of craft suitability in each particular phase. Extreme deviations could possibly invalidate the results. To set some finite bound on craft values a scale from 0 to 10 was arbitrarily chosen. Increasing values indicate better performance and represent a higher degree of preference for the associated craft.

The actual scaling involved taking the raw score of the "best performing resource" and converting other craft scores to fractions by dividing by this largest score. If the "best" performance is signified by the smallest raw score, the inverse of these scores was first taken and then the above rationale applied. The final manipulation was to multiply each of the fractions by 10 to scale the values.

For response, the times are converted into fractions of hours. Since a minimum response time is the desirable feature, the inverse of these times was first taken. Then by dividing by the largest number and multiplying by the scale factor 10, the values in the previous table were obtained.

Craft performance in the transit phase of SAR operations is a function of speed. The speed of a vessel depends not only on the physical design characteristics but also on the operating environment, primarily sea state for surface craft and wind for the helicopter. Wind velocities less than 60

knots do not seriously impair the operations of helicopters. Since winds exceeding 30 knots were encountered only 1.7 per cent of the time, helicopter transit was, for this analysis, unaffected by wind and sea conditions. Acknowledging the dependence of sea state upon wind, it was assumed that for surface craft, sea state is the limiting factor in SAR operations. The geographical area of transit was assumed to be feasible for all resources. Draft restrictions and the like for certain "close in" incidents are irrelevant, because prosecution of these type cases could be carried out by smaller craft currently in the resource inventory. For congruity, the wave heights have the same division points as later used in the formulation of the workload matrix. All applicable cases for the three-year period were analyzed and categorized according to sea states and type of assisting resource. These are listed in the following table.

	WAVE HEIGHT IN FEET		
	0-3	3-10	>10
PERCENT OF TIME SEA STATES OBSERVED	60.4	37.9	01.7

The table wave heights were divided into three ranges, and are compatible with data stored on the SAR magnetic tapes. The observed sea states are recorded for actual on-scene search conditions. Though it is conceivable that the sea

states in the transit environment differ from on-scene conditions, the difference is expected to be insignificant. The tendency would definitely be toward calmer seas since part of the transit is spent in sheltered waters. The lower sea states would result in higher speeds for all craft in the transit mode. Because there is no means to determine the sea states under historical transit conditions and because of the unlikelihood that there is any difference between the two areas, on-scene reported sea states were used in the analysis.

The following table lists the division points and symbology to be used in the calculations.

WAVE HEIGHT IN FEET	BEAUFORT SCALE SEA STATES	MAXIMUM SUSTAINABLE SPEED IN SEA STATES
0-3	1-2	S_1
3-10	3-4	S_2
greater than 10	greater than 4	S_3

The next table lists the maximum sustainable speeds by specific resource type in varying sea heights.

		WAVE HEIGHT IN FEET	
RESOURCE	0-3	3-10	>10
FLAGSTAFF	50	45	7
HIGHPOINT	48	42	12
VOYAGEUR	47	0	0
HH-52A	90	90	90
HOVER FERRY	30	0	0
WPB 82'	18	12	6
WPB 95'	18	12	6
WMEC 210'	17.5	16	10

An average maximum operating speed over time for each craft was computed by adjusting the maximum speed by the historical percentage of time cases occur in the various sea states over the three-year data period. Sea conditions remained relatively constant over the time interval of the data and there is no reason to doubt that it will not remain constant for future years. This particular scenario modification makes the craft performance directly applicable to the environmental mission demands. Transit speed can be calculated as follows where:

$$\begin{array}{l}\text{Average Maximum}\\ \text{Transit Speed}\end{array} = \sum_{i=1}^{3} \left(\begin{array}{l}\text{Percent of operating}\\ \text{time in sea state i}\end{array}\right) \times \left(\begin{array}{l}\text{Maximum attainable}\\ \text{speed in sea state i}\end{array}\right)$$

$$TAVE_{(FLAGSTAFF)} = \%P_1S_1 + \%P_2S_2 + \%P_3S_3$$

$$TAVE_{(FLAGSTAFF)} = (0.604)(50Kts) + (0.379)(45\ Kts) + (0.017)(7\ Kts)$$

$$TAVE_{(FLAGSTAFF)} = 47.4\ Kts$$

The table below provides a computational listing of the maximum average speeds for each craft after being adjusted for operating sea states.

RESOURCE	MAXIMUM SPEED IN KNOTS	AVERAGE MAXIMUM SPEED IN KTS SEA STATE ADJUSTED	SCALE VALUE
FLAGSTAFF	50	47.4	6.3
HIGHPOINT	48	45.1	6.0
VOYAGEUR	47	28.4	3.8
HH-52A	90	75.0	10.0
HOVER FERRY	30	18.1	2.4
WPB 82'	18	15.5	2.1
WPB 95'	18	15.5	2.1
WMEC 210'	17.5	16.8	2.2

The time spent searching often varies from minutes to the craft's maximum endurance. A craft's search performance capability is similar to transit in that it is primarily dependent upon speed and sea state. Crew vigilance, platform stability, and many other factors affect the outcome of the

search effort. It is realized that these are important considerations, but are assumed equal for all craft in the search phase analysis. These features are partially handled in the subjective assistance phase analysis and will directly determine those scale values for each resource. A fixed search scenario can be used to evaluate the performance of each craft. The associated environmental conditions to be assumed are:

1. Ten knot wind
2. Ten mile visibility
3. Thirty percent cloud coverage

First day searches are normally designed to achieve a coverage factor of one (1). Coverage factor (C) is related to sweep width (W) and track spacing (TS) per the following equation of Ref. 1.

$$C = W/TS$$

For a known visibility and a prescribed search altitude, the sweep width can be determined from Table I for any type of search object. For this scenario, the sweep width for a helicopter operating at 500 feet searching for a small boat is 3.9 nautical miles. For a surface craft the value is 4.0 nautical miles. When the nomograph is used to determine the track spacing, the difference between 3.9 and 4.0 is not discernible. Therefore a W value of 4.0 nautical miles is

Sweep Width (W) For Visual Search

(W Given In Nautical Miles)

Meteorological Visibility - Nautical Miles / Altitude 100 ft	LIFERAFTS 0	LIFERAFTS 5	LIFERAFTS 10	LIFERAFTS 20	BOATS (less than 30') 0	BOATS (less than 30') 5	BOATS (less than 30') 10	BOATS (less than 30') 20	BOATS (less than 30') 30
1	0.5	0.5	0.5	-	0.5	0.5	0.5	-	-
3	1.0	1.2	1.2	1.0	2.5	2.4	2.3	1.8	0.4
5	1.4	1.6	1.6	2.7	2.7	2.7	2.7	3.2	3.3
10	1.8	1.8	2.1	3.6	3.9	4.0	4.2	4.5	5.8
15	1.9	1.9	2.6	3.6	5.2	5.3	5.5	6.7	7.0
20	2.0	2.1	2.8	3.6	5.3	5.6	6.2	6.8	7.1
30	2.2	2.3	2.9	3.6	5.5	6.2	7.0	7.0	7.1
40	2.2	2.4	2.9	3.6	5.6	6.3	7.1	7.1	7.2
50	2.2	2.4	3.0	3.6	5.7	6.4	7.2	7.2	7.3

Meteorological Visibility - Nautical Miles / Altitude 100 ft	BOATS (30'-60') 0	BOATS (30'-60') 5	BOATS (30'-60') 10	BOATS (30'-60') 20	BOATS (30'-60') 30	BOATS (60'-90') 0	BOATS (60'-90') 5	BOATS (60'-90') 10	BOATS (60'-90') 20	BOATS (60'-90') 30
1	0.5	0.5	0.5	-	-	1.0	0.5	0.5	-	-
3	3.5	3.0	2.7	1.8	0.4	3.9	3.4	3.2	1.8	0.4
5	4.2	4.2	4.2	4.2	3.3	5.0	5.0	4.9	4.7	3.3
10	6.5	6.2	6.2	6.2	6.5	8.0	8.0	7.9	7.7	7.2
15	8.5	8.5	8.4	8.4	8.3	11.0	9.9	9.6	9.1	8.5
20	8.6	8.8	9.0	9.1	8.9	12.0	11.0	10.6	10.0	9.3
30	8.7	9.5	10.4	10.1	9.7	12.5	12.5	12.1	11.3	10.5
40	8.9	10.0	11.0	10.8	10.3	13.0	13.0	13.2	12.2	11.3
50	9.0	10.0	11.9	11.3	10.7	13.5	13.5	14.0	13.0	11.9

Meteorological Visibility - Nautical Miles / Altitude 100 ft	SMALL SHIPS (500-5000 Gross Tons) 0	5	10	20	30	MEDIUM SHIPS (5000-10,000 Gross Tons) 0	5	10	20	30	LARGE SHIPS (Over 10,000 Gross Tons) 0	5	10	20	30
1	1.0	1.0	1.0	-	-	1.0	1.0	1.0	-	-	1.0	1.0	1.0	-	-
3	4.2	3.8	3.2	1.8	0.4	4.6	4.0	3.3	1.8	0.4	4.7	4.0	3.3	1.8	0.4
5	7.1	6.7	6.2	4.9	3.3	8.0	7.0	6.2	4.9	3.3	8.0	7.0	6.5	4.9	3.3
10	11.0	10.0	9.8	3.6	7.2	11.0	10.6	10.2	9.0	7.2	11.0	10.6	10.2	9.1	7.2
15	13.4	12.7	12.0	10.5	9.1	14.0	13.7	13.3	11.4	9.4	14.0	13.9	13.7	11.6	9.5
20	15.0	14.3	13.5	11.9	10.4	15.0	15.0	15.1	13.0	10.9	15.0	15.0	15.6	13.3	11.1
30	17.0	16.5	15.7	13.9	12.2	17.0	17.0	17.0	15.4	13.1	17.0	17.0	17.0	15.8	13.4
40	17.0	17.0	17.2	15.3	13.5	17.0	17.0	18.0	17.1	14.7	17.0	17.0	18.0	17.5	15.0
50	20.0	19.3	18.4	16.4	14.5	20.0	21.0	20.8	18.3	15.9	20.0	21.0	21.0	15.9	16.5

WHITECAP CORRECTION FACTOR (f_w)

WIND (kts)	0	10	15	20	25	30	10	50	60
Rafts	0.8	1.0	0.9	0.7	0.5	0.2	0.1	-	-
Boats	0.9	1.0	1.1	1.0	0.9	0.7	0.2	-	-
Ships	1.1	1.0	1.0	0.9	0.8	0.7	0.5	0.2	-
Dye Marker	0.9	1.0	1.0	0.9	0.6	0.4	0.2	-	-
Smoke	0.8	1.0	0.8	0.6	0.4	0.2	0.1	-	-

LIGHTING CORRECTION FACTOR (f_l)

Percent Cloud Cover	0	10	20	30	10	50	60	70	80	90	100
Cloud Cover Factor	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.8	0.7

TABLE I

assumed as fixed for both vessels on the surface and airborne helicopters. To achieve a coverage factor of 1.0 the search planner merely assigns the track spacing to be equal to the search width. With this mile track spacing the area searched in one hour by a 75 knot helicopter is determined to be approximately 280 square miles using the nomograph of Figure I. The comparative effectiveness of other craft can be determined by calculating the time required to search this fixed size area by using the speedy helicopter as a standard. This is done by entering the nomograph with the speed of the craft and the fixed area (280 sq. mi.) and reading the time required to complete the search. The results are listed below.

RESOURCE	TIME REQUIRED TO SEARCH 280 SQ. MI. (in Hrs.)	SCALE VALUE
FLAGSTAFF	1.40	7.1
HIGH POINT	1.42	7.0
VOYAGEUR	2.30	4.3
HH-52A	1.00	10.0
HOVER FERRY	3.20	3.1
WPB 82'	3.60	2.8
WPB 95'	3.60	2.8
WMEC 210'	3.5	2.9

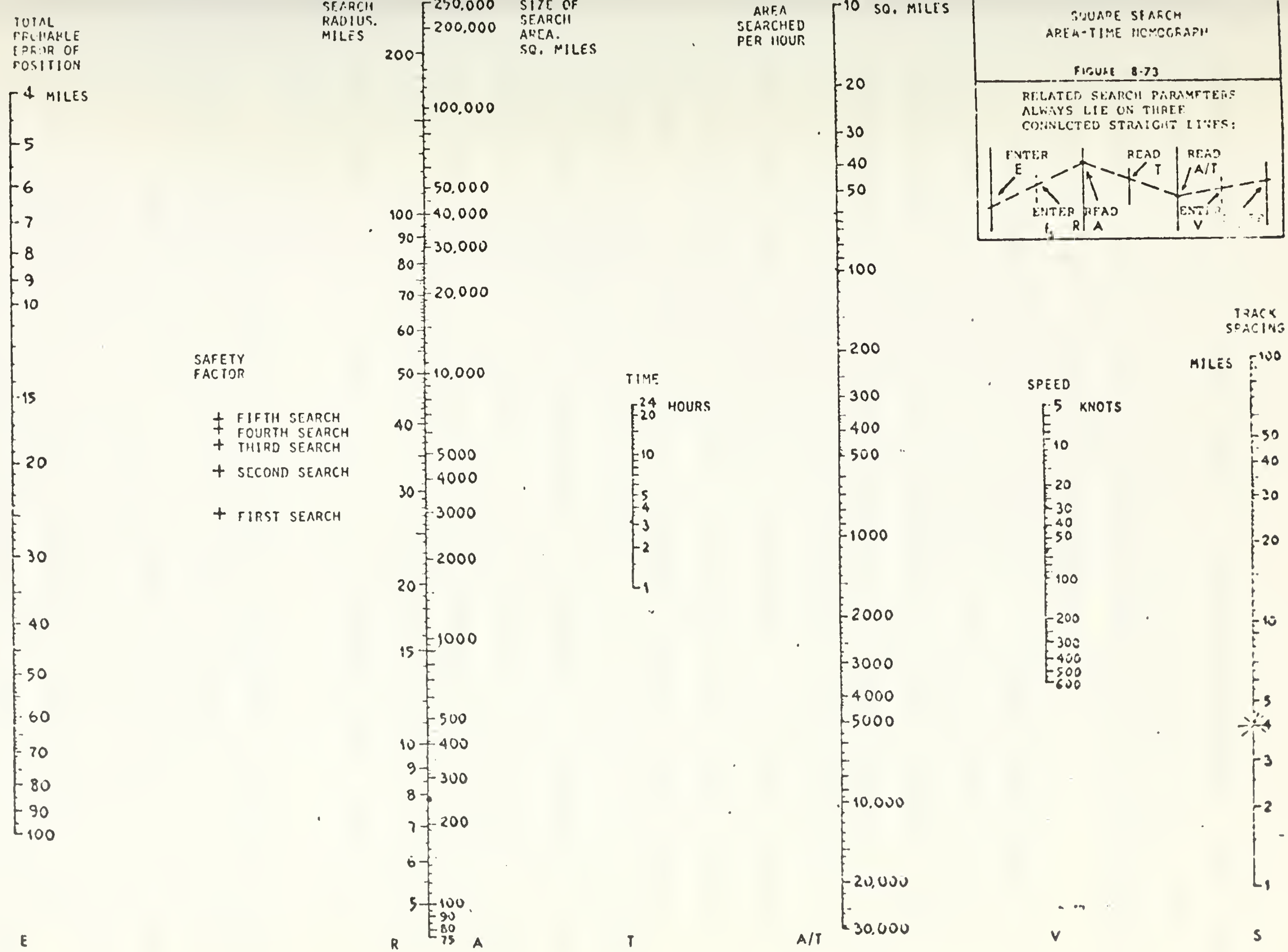


FIGURE I. Search Area-Time Nomograph

Scale values are calculated as described earlier. The "best performer" is the one with the shortest search time. The inverse of each craft's expected search time is multiplied by 10 to yield the tabled scale values.

Craft performance in rendering on-scene assistance is impossible to quantify objectively because of the nature of operations. Effectiveness depends on craft features such as maneuverability, platform stability, draft restrictions, and many others. Though these performance characteristics can be quantified generally for any vessel, it is not possible to relate the actual value in the SAR tasks which are performed. For example does a smaller turning radius mean a certain task can be done better? If so, how much? Because of these problems, a subjective approach of evaluating the craft was taken, relying on the authors' experience as well as other Coast Guard operational personnel for rating criteria. Where experience was lacking, technical reports and published papers were used in estimating craft assistance performance.

The nine original operational assistance categories were aggregated into five sub-categories according to the similarity of tasks involved in performing the mission. For instance, delivering supplies and evacuating personnel require the same craft capabilities to assure successful execution of the assistance. To maintain compatibility with the other three phases each craft was subjectively rated on a scale from 0 to

10 according to its suitability in the applicable SAR situations. The next table includes these scale values based on the pertinent comments accumulated from available technical reports and from operational experience.

For navigation and communications assistance each craft is considered to be equally capable because the assistance is dependent upon the equipment installed aboard and the same can be installed on all craft.

The scale values for all four phases are presented in matrix form below. This matrix will be referred to as the scale matrix ($\phi_{\alpha j}$).

PHASES	FLAG-STAFF	HIGH-POINT	VOYAGEUR	HH52A	HOVER FERRY	WPB 82	WPB 95	WMEC 210
RESPONSE	4.0	4.0	6.7	10.0	6.7	5.0	5.0	1.7
TRANSIT	6.3	6.0	3.8	10.0	2.4	2.1	2.1	2.2
SEARCH	7.1	7.0	4.3	10.0	3.1	2.8	2.8	2.9
ASSISTANCE 1	4.0	4.0	2.0	8.0	2.0	6.0	6.0	6.0
ASSISTANCE 2	4.0	4.0	4.0	0.0	4.0	10.0	10.0	10.0
ASSISTANCE 3	4.0	4.0	4.0	8.0	4.0	6.0	6.0	6.0
ASSISTANCE 4	2.0	2.0	6.0	0.0	6.0	10.0	10.0	10.0
ASSISTANCE 5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

SCALE MATRIX ($\phi_{\alpha j}$)

Summarizing, the scale matrix ($\phi_{\alpha j}$) contains dimensionless values indicating craft performance in the different

	HYDROFOILS	ACV/SES	HH-52A	CONVENTIONAL CRAFT
SEARCH (A1)	high speed most sea states stable search platform medium range shallow water restricted poor visibility 4	high speed in low sea states high sea state limited operation short range noisy poor visibility 2	high speed bad weather limited excellent search platform unaffected by sea conditions 8	all weather capability low speed stable platform long range 6
TOW AND ESCORT (A2)	hard to rig tow poor low speed maneuverability stable towing platform 4 underpowered for towing operations limited speed range	hard to rig tow poor maneuverability throws spray at low speeds unstable boarding and towing platform 4	slow escort not feasible no actual towing capability 0	excellent speed range stable boarding and towing platform 10 excellent maneuverability
DELIVER SUP. AND EVAC. PERSONNEL (A3)	poor low speed maneuverability stable boarding platform 4	noisy throws spray poor low speed maneuverability 4 poor boarding platform	unaffected by seas bad weather limited 8 capacity limited	stable platform all weather operations 6
REFLOAT DEWATER FIGHT FIRES (A4)	poor low speed maneuverability shallow water limited 2	poor low speed maneuverability excellent shallow water capability 6	can't assist 0	good maneuverability versatility offered by equipment carried 10
NAVIGATION AND COMMUNICATIONS (A5)	equipment dependent 5	equipment dependent 5	equipment dependent 5	equipment dependent 5

phases of a mission. There are four phases with the fourth broken down into five sub-categories. A score of 0 implies complete inability of a resource to perform the phase tasks. Similarly, a score of 10 in each of the first three phases means that the associated resource out performs all other craft in that particular phase. In the fourth phase, subjective values were assigned to craft using the same scale (0-10). For instance, in towing and escort (Assist 2), the conventional vessels are ideally equipped to perform this task and were assigned a value of 10. Insignificant differences exist between the high speed surface craft which are equally rated to be forty percent as effective as the best towing craft. For some of the assistance sub-categories the top score is less than 10. This is meant to indicate some inability of the craft to perform the phase tasks. As an example the helicopter is the best search vehicle, but is bad weather limited so it has a score of only 8. Other craft were then rated comparatively according to this standard as the best score.

If the only consideration were scale values then the most desirable craft would be the one with the highest cumulative score in the four phases. Using this rationale the obvious choice for a search vehicle from the scale matrix is the helicopter with a total score of 38. But as will be seen in the next section, the proportion of time actually spent in each phase directly affects how important the individual phase values are in the ultimate determination of a suitable craft.

B. TIME WEIGHTING MATRIX

The time weighting matrix ($\%_{k\alpha}$) is a display of the per cent of total sortie time in all SAR categories (k) which is spent in each phase (α) of the SAR mission. Response times were available indirectly from the SAR records by subtracting "time notified" from "time underway". Transit times were obtained in a similar manner by subtracting "time underway" from "time on scene or arrival in search area". Search time and time actually spent on scene rendering assistance are not reported statistics on CG-3272. However, "total time on sortie" is reported explicitly, and with this information, search and on-scene times can be estimated, as below. The following table of times (in hours) was obtained from the SAR data with respect to WPB's:

	Response time (hrs)	Transit time (hrs)	Total time (hrs)
Search, large object	.29	1.14	4.93
Search, small object	.30	1.27	6.10
Tow and/or escort	.25	1.43	4.56
Deliver supplies	.21	1.09	3.31
Evacuate personnel	.30	1.02	3.04
Comm/Nav assist.	.16	1.09	3.44
Refloat	.24	.62	3.00
Dewater	.20	1.32	5.27
Fight fire	.26	1.07	5.06

The following relationship was the basis for the derivation of search and on-scene operations time:

$$\text{Total time} = \text{Response} + (@)\text{Transit} + \text{Search} + \text{On scene assistance}$$

where (@) is determined by the type of assistance rendered.

From this, the sum of search time and on scene operations time is found directly. The fractional division of this lumped time is a matter of subjective evaluation and varies with each type of SAR case. General guidelines do exist in that CNA [Ref. 3] has shown that about 25% of the time the Coast Guard assisting resource spends more than thirty minutes in the search mode. This information was available to CNA since their data was from the years 1967 to 1969 when "search time" was a reported statistic on CG-3272. It has since been revised, and "search time" is no longer reported. The CNA study was based on all existing resources, not just the WPB. For CNA, the average search time per sortie was 49.8 minutes. The Study for Alerting and Locating Techniques and Their Impact [Ref. 4], hereafter referred to as SALTTI, reported a figure of 45 minutes per sortie for cases involving towing, and 65 minutes per sortie for non-towing cases. SALTTI estimates were made for the WPB in particular. Weighting these two figures by the number of towing and non-towing cases (FY73) gave an average search time per sortie of 50.7 minutes.

For the SAR category, "Search, large object", the transit coefficient (@) is two since the nature of assistance rendered

would not hinder return transit. Consequently, the total transit time is merely twice (@=2) the outbound transit time. When all accounted-for time periods are subtracted from the total time spent on the sortie, the remaining time period is the sum of search time and on-scene assistance time. Since this SAR category implies a minimum of time spent rendering assistance (the search itself is the assistance rendered), and in view of the large number of searches where the objective is location and not subsequent rescue, the division of the remaining time period is chosen to 90%/10% in favor of search time. The same reasoning applies to the category "Search, small object". Therefore, these two SAR classifications have been broken down into the following time frames:

	response time (hrs)	one-way transit time (hrs)	search time (hrs)	on-scene time (hrs)
Search, large obj.	.29	1.14	.9(4.93-.29-2(1.14)) = 2.12	.1(4.93-.29-2(1.14)) = .24
Search, small obj.	.30	1.27	.9(6.10-.30-2(1.27)) = 2.93	.1(6.10-.30-2(1.27)) = .33

For the SAR category "tow and escort" the term "(@) transit" is replaced by "transit + 2.13". This was developed by assuming that, in cases involving towing and/or escorting (towing and escort speeds are assumed the same) the total transit time is the outbound transit time plus the time

required for the inbound transit of the "average" tow or escort. The time involved with the "average" tow or escort proved to be the quotient of the average distance towed and the (estimated) average towing speed:

$$\frac{21.3 \text{ miles}}{10 \text{ knots}} = 2.13 \text{ hours}$$

In the original notation, this is equivalent to:

$$@ \text{ transit} = \text{transit} + 2.13$$

$$@ = \frac{\text{transit} + 2.13}{\text{transit}} = \frac{1.43 + 2.13}{1.43} = 2.5$$

(which indicates that return transit time is 1.5 times the outbound transit time)

From SALTTI, optimistic and pessimistic estimates of time spent on-scene during towing operations were made for WPBs:

	on-scene assistance time		
unit type	optimistic	pessimistic	average
WPB	20 minutes	40 minutes	30 minutes (0.5 hr)

Search time is now the only unaccounted for time period in the total time equation and can be found by subtraction.

Therefore, the "tow and/or escort" section is broken down into the following time frames:

	response time (hrs)	one-way transit time (hrs)	search time (hrs)	on-scene time (hrs)
Tow and/or Escort	.25	1.43	4.56-.25-2.5(1.43) = .235	.5

For the categories "deliver supplies", "evacuate personnel" and "communications and navigation assistance" it is no longer necessary to look at data from WPB cases only. For the "deliver supplies" operation, practically any existing resource is suitable, and it may be reasonably assumed that this activity is performed uniformly in efficiency and frequency by the current resource inventory. Consequently, the search time estimate used for this SAR category is from SALTTI and represents the servicewide average search time per sortie. The assistance types "evacuate personnel" and "communications and navigation assistance" represent operations that are performed predominantly by helicopters and other air resources. Again, SALTTI estimates for search time per sortie were used considering helicopter cases for "evacuate personnel" and all air resources for "communications and navigation assistance". Therefore these three categories are broken down as follows, assuming @ = 2:

	response time (hrs)	one-way transit time (hrs)	search time (hrs)	on-scene assistance time (hrs)
deliver supplies	.21	1.09	.71	3.31-.21-2(1.09)-.71 = 0.21
evacuate pers.	.30	1.02	.34	3.04-.30-2(1.02)-.34 = 0.36
comms/nav assist	.16	1.09	.58	3.44-.16-2(1.09)-.58 = 0.52

For the remaining three categories of "refloat", "dewater", and "fight fire", the transit coefficient (@) takes on a meaning similar to that described in the "tow and escort" section. For these cases it is estimated that rescue efforts will result in success 70% of the time, which will then require tow or escort services on the inbound transit leg. Therefore the total transit time will be composed of the outbound transit time plus the identical time for inbound transit 30% of the time, and outbound transit plus 1.4 times that transit time 70% of the time:

$$@ = 2(0.3) + 2.5(0.7) = 2.35$$

After all time accounted for in the time equation is subtracted from the total sortie time, the remaining time is composed of the sum of search and on-scene operations time, as before. Both Ref. 3 and Ref. 4 determined the average search time for these cases to be approximately 50

minutes per sortie. Using this estimate the three categories are broken down as follows:

	response time (hrs)	one-way transit time (hrs)	search time (hrs)	on-scene assistance time (hrs)
refloat	.24	.62	.83	3.00-.24-2.35(0.62)-.83 = 0.47
dewater	.20	1.32	.83	5.27-.20-2.35(1.32)-.83 = 1.14
fight fire	.26	1.07	.83	5.06-.26-2.35(1.07)-.83 = 1.46

Recapping the computations performed to this point yields:

	response time (hrs)	@	transit time (hrs)	search time (hrs)	on-scene assistance time (hrs)	total time (hrs)
search, large obj.	.29	2	1.14	2.12	.24	4.93
search, small obj.	.20	2	1.27	2.93	.33	6.10
tow and escort	.25	2.5	1.43	0.235	.50	4.56
deliver supplies	.21	2	1.09	0.71	.21	3.31
evacuate personnel	.30	2	1.02	0.34	.36	3.04
comm/nav assist.	.16	2	1.09	0.58	.52	3.44
refloat	.24	2.35	0.62	0.83	.47	3.00
dewater	.20	2.35	1.32	0.83	1.14	5.27
fight fire	.26	2.35	1.07	0.83	1.46	5.06

The total time spent on a case in each category is divided into the four phases of response, transit, search and assist

in the proportions indicated by the data. To allocate the time to each phase properly, a modification to the (@) term is made. In those categories where return transit is not slowed by the nature of the assistance rendered (@=2) is the multiplier of "transit" in the following calculations. In those cases where the assistance rendered affects the return transit, the multiplier of "transit" is one (representing outbound transit), and the on-scene operations element is augmented by a factor of ((@ - 1) x transit). This accounts for those circumstances (towing, for example) where on-scene operations continue beyond the scene of the incident and might otherwise be considered incorrectly as an element of "unencumbered" transit.

The matrix of average time spent in each phase of every SAR category is constructed as follows:

	response (hrs)	transit (hrs)	search (hrs)	assist (hrs)
search, large obj.	.29	2(1.14) = 2.28	2.12	.24
search, small obj.	.30	2(1.27) = 2.54	2.93	.33
tow and escort	.25	1(1.43) = 1.43	0.24	.5 + 1.5(1.43) = 2.65
deliver supplies	.21	2(1.09) = 2.18	0.71	.21
evacuate personnel	.20	2(1.02) = 2.04	0.34	.36
comm/nav assist.	.16	2(1.09) = 2.18	0.58	.52
refloat	.24	1(0.62) = 0.62	0.83	.47 + 1.35(0.62) = 1.31
dewater	.20	1(1.32) = 1.32	0.83	1.14 + 1.35(1.32) = 2.92
fight fire	.26	1(1.07) = 1.07	0.83	1.46 + 1.35(1.07) = 2.91

The intent of a matrix of this configuration is to weight the scale matrix of performance characteristics to give appropriate emphasis on each phase in every SAR category. For example, a WPB 95 was rated in performance in response, transit, search and assistance by four separate scores. To evaluate the WPB 95 in the SAR category "evacuate personnel" the four performance scores are rated in the proportions 10% (response), 67% (transit), 11% (search), and 12% (assistance). These per cents were found by dividing each element of the row "evacuate personnel" in the above matrix by the row sum. The intention is to emphasize the performance scores in proportion to the expected duration of the actual phases.

At this point it became apparent that the above matrix did not function as intended except in the evaluation of a WPB (recall that the data that generated this matrix was obtained from WPB cases). It is incorrect to weight hydrofoil transit by 67% since the hydrofoil transits much faster than the WPB and will consequently spend much less of a per cent of total time in the transit mode. The factor that remains constant while resources vary is the distance traveled both in the transit and search phases, not the time. Likewise it may not be appropriate to weight hydrofoil response by 10% since it spends a longer period of time in the response mode than does the WPB, and it may be expected that the percentage of total time in the response mode for

the hydrofoil would be different from the WPB. It is assumed that the length of time spent on-scene rendering assistance is entirely a function of the type of assistance required, and is unaffected by the type of resource rendering it. Consequently the data derived from the WPB cases is good for all resources. Any differences among the various resources in ability to handle certain types of assistance is accounted for in the scale matrix.

Two modifications to the matrix are necessary to insure that it properly weights the performance matrix:

1) Since the transit and search time figures already generated concern WPB cases only, and the average WPB speed is easily obtained, transit and search distances can be found. This is done by multiplying the transit and search columns of the matrix in question by 15.5 knots, which is the average WPB speed. In matrix notation the above computation would appear as is shown on the following page.

It is this matrix that will form the basis for all further computations and upon which the second modification will be performed:

2) Since the average response times for each resource to be evaluated are known from appropriate references (and available from scale matrix computations) their values should be reflected in the response column. This is done by multiplying the response time column

	Response time (hrs.)	Transit time (hrs.)	Search time (hrs.)	Assist time (hrs.)
Search, large object	.29	2.28	2.12	.24
Search, small object	.30	2.54	2.93	.33
Tow and/or escort	.25	1.43	.24	2.65
Deliver supplies	.21	2.18	.71	.21
Evacuate personnel	.30	2.04	.34	.36
Comm/Nav assistance	.16	2.18	.58	.52
Refloat	.24	.62	.83	1.31
Dewater	.20	1.32	.83	2.92
Fight fire	.26	1.07	.83	2.91

X

1	0	0	0
0	15.5	0	0
0	0	15.5	0
0	0	0	1

=

	Response time (hrs.)	Transit time (hrs.)	Search time (hrs.)	Assist time (hrs.)
Search, large object	.29	35.3	32.9	.24
Search, small object	.30	39.4	45.4	.33
Tow and/or escort	.25	22.2	3.7	2.65
Deliver supplies	.21	33.8	11.0	.21
Evacuate personnel	.30	31.6	5.3	.36
Comm/Nav assistance	.16	33.8	9.0	.52
Refloat	.24	9.6	12.9	1.31
Dewater	.20	20.5	12.9	2.92
Fight fire	.26	16.6	12.9	2.91

of the matrix in question by X/20, where X is the average response time of the resource under consideration and 20 is the average response time of the WPB.

The aforementioned computation, in matrix notation, incorporates modifications one and two and yields a matrix representing the amount of time spent in the α^{th} phase during the k^{th} type of SAR activity. This matrix is shown on the next page, and it is empty since the values to be observed depend on the particular resource in question. In particular, "X" and "speed" refer directly to the craft under consideration.

This matrix, where all four phases have the dimension "time", are transformed into the $\%_{k\alpha}$ matrix by dividing each element by its respective row sum. The $\%_{k\alpha}$ matrix reflects the per cent of time the resource under consideration spends in the α^{th} phase of SAR for the k^{th} type of SAR incident. The $\%_{k\alpha}$ matrix for the WPB and the hydrofoil (hydrofoil speed is assumed to be 40 knots and average response time is assumed to be 25 minutes) are shown as follows for comparison:

	Response time (hrs.)	Transit time (hrs.)	Search time (hrs.)	Assist time (hrs.)
Search, large object	.29	35.3	32.9	.24
Search, small object	.30	39.4	45.4	.33
Tow and/or escort	.25	22.2	3.7	2.65
Deliver supplies	.21	33.8	11.0	.21
Evacuate personnel	.30	31.6	5.3	.36
Comm/Nav assistance	.16	33.8	9.0	.52
Refloat	.24	9.6	12.9	1.31
Dewater	.20	20.5	12.9	2.92
Fight fire	.26	16.6	12.9	2.91

X

X/20	0	0	0
0	$\frac{1}{speed}$	0	0
0	0	$\frac{1}{speed}$	0
0	0	0	1

=

	Response time (hrs.)	Transit time (hrs.)	Search time (hrs.)	Assist time (hrs.)
Search, large object				
Search, small object				
Tow and/or escort				
Deliver supplies				
Evacuate personnel				
Comm/Nav assistance				
Refloat				
Dewater				
Fight fire				

$\gamma_{k\alpha}$ matrix

$\%_{k\alpha}$ matrix for WPB:

	Response	Transit	Search	Assist
Search, large	.06	.46	.43	.05
Search, small	.05	.42	.48	.05
Tow/escort	.05	.32	.05	.58
Del. supplies	.06	.66	.22	.06
Evac. pers.	.10	.67	.11	.12
Comm/nav	.05	.63	.17	.15
Refloat	.08	.21	.28	.43
Dewater	.04	.25	.16	.55
Fight fire	.05	.21	.16	.58

$\%_{k\alpha}$ matrix for hydrofoil:

	Response	Transit	Search	Assist
Search, large	.16	.38	.36	.10
Search, small	.13	.35	.41	.11
Tow/escort	.09	.16	.03	.72
Del. supplies	.16	.53	.18	.13
Evac. pers.	.23	.48	.08	.21
Comm/nav	.11	.47	.13	.29
Refloat	.14	.11	.15	.60
Dewater	.06	.13	.08	.73
Fight fire	.08	.11	.08	.73

One general comment is in order before proceeding. The data in the "response time" column represents the average time from notification of a SAR incident until the WPB is

underway. Attempts were made to find average response times for other resources from the SAR tapes, but the results were not intuitively consistent. For example, the data indicated that the 210 foot WMEC averaged between 5 and 10 minutes for response. Experience indicates that response for this resource would more realistically be measured in terms of hours, so the resulting average response time from the SAR tapes is considered grossly in error. An explanation for this result is that perhaps in a large number of WMEC cases the resource was already underway on patrol upon the occurrence of the SAR incident. Assuming this to be true (there is no way to verify this by the data), the figure obtained is more appropriately labeled "time to divert" rather than time to transition from a "cold iron" status to underway. Similar erroneous data was observed in helicopter cases where experience indicates this resource usually responds rapidly, but the data unexplainably rated it equivalent to the WPB. Only in the case of the WPB did the SAR tapes yield results that were commensurate with the authors' experience. Therefore the WPB response data was used, and individual response differences among varying resources was accounted for in the scale matrix.

Referring to the matrices just constructed, it is observed that the per cent of time that the hydrofoil spends in transit is less than that for the WPB due to the greater speed capability of the hydrofoil. Likewise, the per cent of total

time the hydrofoil spends in response is greater than that of the WPB because total case time is less and response time is larger for the hydrofoil.

Note that in comparing the $\%_{k\alpha}$ matrix for the WPB and the hydrofoil, the differences in the transit columns are in the direction expected but possibly not in the magnitude expected to be observed from almost a 3 to 1 speed ratio. This is due to the fact that SAR incidents in general do not occur great distances from shore. Since the Coast Guard stations are located in areas of high density boating populations, it follows that SAR incidents do not generally occur at great distances from rescue stations. Consequently the high speed characteristics of the hydrofoil are only partially observable in terms of per cent of time in each phase of the SAR mission. (This hints that perhaps the hydrofoil, to be more fully utilized, should undertake Coast Guard operations in missions other than SAR where longer transit distances are inherent.)

In summary of this section, the $\%_{k\alpha}$ matrix (the per cent of time spent in the α^{th} phase of SAR in the k^{th} category of SAR activity) is derived for every resource under consideration whose speed and response characteristics are unique. When post-multiplied by the ϕ_α vector corresponding to the resource under consideration and a simple probability term (to be explained in the next section), the result is the P_k vector representing the performance scores of the j^{th} resource in all k SAR categories.

C. THE WORKLOAD MATRIX

Two characteristics which effect the handling of a SAR case are the distance to the scene of the incident and the degree of severity that is implied by the nature of the distress. In the first instance, Ref. 3 showed that 45% of all SAR cases occur within five miles of the assisting resource, and that about two-thirds of all cases occur within about 10 miles. Since the CNA analysis included all Coast Guard resources, it was felt that the numerous cases (65% of the total) involving assistance rendered by motor life boat or utility boat caused the "distance to scene" results to be too low for the purpose of this work. Using the data available, the 235,000 cases on file were sorted into those handled by the WPB's, WMEC and helicopters since these resources more readily reflect the type of case that is apt to be encountered by any of the non-conventional craft to be evaluated in this study. This data sorting yielded the following:

distance to scene	% cases	cumulative % cases
0 - 3 miles	13.5%	13.5%
3 - 25 miles	47.5%	61.0%
> 25 miles	39.0%	100.0%

By comparison, the CNA study showed that about 15% of all Coast Guard SAR cases were responded to by WPB, WMEC or helicopters during the three year period 1967 to 1969.

Analysis of the data for the three year period from 1971 to 1973 indicate a figure of approximately 11%. This may substantiate the effects of increased age and consequent reduced reliability of the WPB, WMEC and helicopters. This 4% reduction in response by medium-sized resources may also hint that steady growth in recreational boating populations (and SAR activity involving those small vessels) has tended to decrease the per cent of cases handled by Coast Guard medium endurance/range craft. A combination of these two hypotheses is also viable.

Severity is reported as the subjective evaluation of the Coast Guard assisting crew upon arrival on scene of the SAR incident. It is reported twice, once with respect to the property involved and again with respect to personnel. Three severity codes were used, and they are defined in CG-397 (Search and Rescue Reports Manual) as follows:

<u>Small</u> - none or slight severity; no immediate or foreseeable danger to property or personnel

<u>Moderate</u> - reasonable to assume that property or personnel might have been lost

<u>Great</u> - likely that property or personnel would have been, or were, lost

Severity conditions were considered from the same two sources that yielded the "distance to scene" figures. The CNA analysis of the years from 1967 to 1969, looking at all resources, is shown for comparison only. The data, sorted as mentioned earlier, from the SAR tapes of 1971 through 1973 will be used for the same reason that applied to the "distance to scene" discussion.

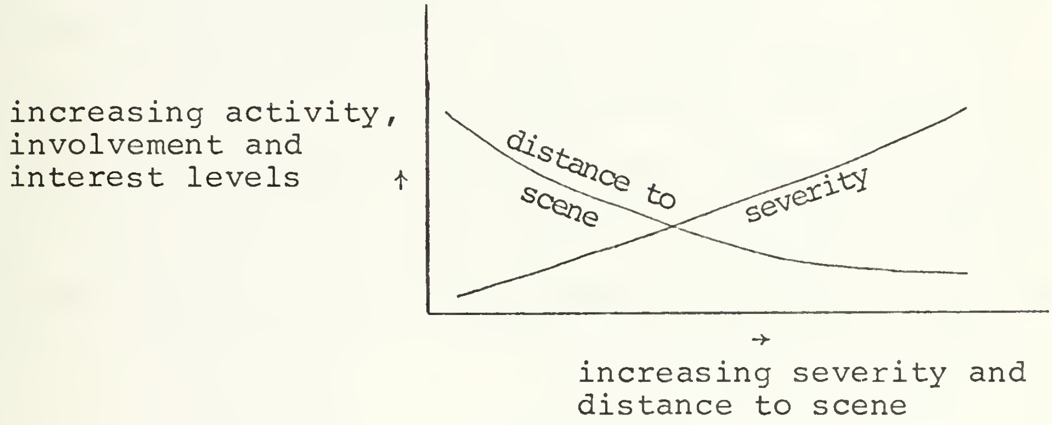
	CNA (1967-1969)		(1971 - 1973)	
severity	%	cum. %	%	cum. %
small	67.2%	67.2%	50.4%	50.4%
moderate	19.7%	86.9%	23.0%	73.4%
great	13.1%	100.0%	26.6%	100.0%

In considering all WPB, WMEC and helicopter cases from 1971 through 1973 with respect to both distance to scene and severity conditions, the following percentages were found:

		severity codes			
		small	moderate	great	total
distance to scene	0-3 miles	8.08%	2.82%	2.63%	13.5%
	3-25 miles	26.60%	9.72%	11.17%	47.5%
	25 miles	15.75%	10.41%	12.82%	39.0%
	Total	50.43%	22.95%	26.62%	100.0%

It was decided that the combination of the two variables (distance to scene and severity) were sufficiently discriminating to warrant their inclusion in the final measures of effectiveness. The "distance to scene" variable reflects some degree of readiness in that during short-distance cases there are no extended periods of inactivity during the transit phase, and even if return transit should involve a tow the distances concerned take relatively little time to traverse. In long-distance cases the routine and almost boring transit phase is compounded by the probability of an even longer inactive

period during an encumbered return transit. The severity variable represents a subjective emotional factor that ranges from relaxed and indifferent for routine cases to excited, active, and deeply involved for life and death situations. The interaction of the two variables is also of interest since, in terms of the individual activity, involvement and interest of the crew, there is some cross-over point as distance to scene and severity increase. This relationship can be shown in an abstract sense as follows:



The categories of SAR activity to be considered in this study cover practically all of the types of assistance that are reportable from CG-397. The only activities not considered were aborted sorties, providing safe conduct, salvage operations, and ice related assistance. Aborted sorties may include several circumstances such as false alarms or assistance that was initially requested by the boater in question but later, before Coast Guard arrival on scene,

declined due to an improving situation (weather) or re-evaluation of the distress itself. Also in this category are those cases where several resources respond to a distress call but, after the position and nature of distress become more certain, some of the assisting resources become unnecessary and are called off the case. By excluding the assistance categories just mentioned, about 70% of all Coast Guard assistance is accounted for. This figure is not impressive until it is realized that 27.5% of the 30% unaccounted for activity represents aborted sorties where no assistance is rendered anyway. Taking this into consideration, about 97.5% of all actual Coast Guard assistance is accounted for.

The CG-397 listings for assistance rendered are shown on the next page. The coding C08 or C09 indicates whether assistance was rendered to personnel or property, respectively.

C08 (assistance rendered to personnel):

01 - searched/failed to locate
02 - searched/located only
03 - searched/rescued
04 - delivered equipment
05 - vectored other unit to scene
06 - provided comms facilities
07 - evacuation (non-medical)
11 - MEDEVAC
12 - provided Doctor and MEDEVAC
13 - provided Doctor
14 - radioed medical advice
15 - delivered medical supplies
16 - rendered first aid only
17 - provided safe conduct
18 - MEDEVAC requiring recompression
50 - sortie aborted for logistics
90 - sortie aborted

C09 (assistance rendered to property):

01 - searched/failed to locate
02 - searched/located only
03 - attempted salvage/failed
04 - recovered property
05 - vectored other unit to scene
06 - provided comms facility
07 - broke ice
08 - refueled/resupplied
09 - gave navigational assistance
11 - fought fire
12 - dewatered
13 - refloated
14 - delivered pump and equipment
15 - made repairs
16 - stood by
20 - towed only
21 - fought fire and towed
22 - dewatered and towed
23 - refloated and towed
24 - delivered pump/equipment and towed
25 - made repairs and towed
26 - stood by and towed
27 - relieved tow
30 - provided escort only
32 - dewatered and escorted
33 - refloated and escorted
36 - stood by and escorted
50 - sortie terminated for logistics
90 - sortie aborted

Nine SAR categories have been chosen such that they include all assistance (except as mentioned previously) classifications listed above. They are described (in code) as follows:

1) Search, large object: C09(1) and C09(2) if case involves vessel over 26 feet in length

2) Search, small object: C08(1) and C08(2) and C08(3) and, if case involves property less than 26 feet in length, C09(1) and C09(2)

3) Tow and/or escort: C09(20) and C09(21) and C09(22) and C09(23) and C09(24) and C09(25) and C09(26) and C09(27) and C09(30) and C09(32) and C09(33) and C09(16)

4) Deliver supplies: C08(4) and C08(15) and C08(16) and C08(13) and C09(8) and C09(14) and C09(15) and C09(24) and C09(25) and C09(32)

5) Evacuate personnel: C08(7) and C08(11) and C08(12) and C08(18)

6) Communications and navigation assistance: C08(5) and C08(6) and C08(14)

7) Refloat: C09(13) and C09(23) and C09(33)

8) Dewater: C09(12) and C09(22) and C09(32)

9) Fight fire: C09(11) and C09(21)

It should be noted that one case may result in two types of assistance rendered. For example, a unit reporting assistance category C09(22) would be credited with having both dewatered and towed as if it were two separate cases. In fact, after the computer sort routine has scanned approximately 235,000 assistance reports selecting for consideration those involving the WPB, WMEC and helicopters, 25,846 cases were analyzed yielding 33,903 assistance entries. Referring to the example of a unit reporting assistance category C09(22), the information on that case is stored under SAR category 8 for "dewatered" and again under SAR category 3 for "tow and/or escort" as if two separate and independent cases had occurred. This is necessary because of the way that the nine SAR categories have been grouped. It is not feasible to do otherwise

since the SAR data does not lend itself to the type of scrutiny necessary to allow combined assistance codes (such as C09(22)) to be considered as assistance rendered wholly in one category and not the other.

The workload matrix W_{ik} represents the proportion of the time that SAR category k (k = 1,...9) occurred in the i^{th} (i = 1,...9) distance/severity zone. The matrix is an array of constants having been found by sorting SAR case information from the years 1971 through 1973.

Initially a matrix is constructed showing the distribution of the number of assistance attempts in the i distance/severity regions and the k SAR categories:

	Search, large object	Search, small object	Tow and/or escort	Deliver supplies	Evacuate personnel	Comm/Nav assistance	Refloat	Dewater	Fight fire
(0-3) miles, small severity	311	537	1213	148	54	324	45	17	1
(0-3) miles, moderate severity	99	191	300	45	87	180	38	37	2
(0-3) miles, great severity	113	262	159	22	98	49	34	40	35
(3-25) miles, small severity	1322	2247	4080	406	144	650	39	35	1
(3-25) miles, moderate severity	438	866	995	263	334	434	63	119	6
(3-25) miles, great severity	745	1585	538	227	500	168	56	100	50
(> 25) miles, small severity	748	1242	2485	241	152	337	20	21	0
(> 25) miles, moderate severity	365	635	956	468	657	303	40	68	2
(> 25) miles, great severity	822	1674	425	323	818	142	33	53	21

Dividing each element by 33,903 (the sum of all the elements) gives the proportion of time that each of the k SAR categories occurred in each of the i distance/severity regions. This is the workload matrix, W_{ik}:

	Search, large object	Search, small object	Tow and/or escort	Deliver supplies	Evacuate personnel	Comm/Nav assistance	Refloat	Dewater	Fight fire
(0-3) miles, small severity	9.17	15.83	35.76	4.36	1.65	9.55	1.33	.50	.03
(0-3) miles, moderate severity	2.92	5.63	8.84	1.33	2.57	5.31	1.12	1.09	.06
(0-3) miles, great severity	3.33	7.72	4.69	.65	2.92	1.44	1.00	1.18	1.03
(3-25) miles, small severity	38.97	66.24	120.27	11.97	4.25	19.16	1.15	1.03	.03
(3-25) miles, moderate severity	12.94	25.59	29.33	7.75	9.85	12.79	1.86	3.51	.18
(3-25) miles, great severity	22.02	46.87	15.86	6.72	14.77	4.95	1.65	2.95	1.47
(> 25) miles, small severity	22.05	36.61	73.25	7.10	4.48	9.93	.59	.62	0
(> 25) miles, moderate severity	10.76	18.72	28.18	13.80	19.40	8.93	1.18	2.00	.06
(> 25) miles, great severity	24.23	49.38	12.53	9.52	24.23	4.19	.97	1.56	.62

(Note: a scalar factor of 10^{-3} has been suppressed)

In summary of this section, the workload matrix, W_{ik} (the proportion of the time that the k^{th} SAR category occurred in the i^{th} distance/severity region) is constructed by sorting

SAR case information from the appropriate 33,903 records by SAR category and distance/severity zones, and then multiplying this array by the scalar 1/33,903. The resulting proportions are based solely on historical data.

D. ANALYTIC MODEL

The following notation applies to the discussion of the general analytic model presented in this study:

$i = i^{th}$ distance/severity region ($i = 1,....9$)

$j = j^{th}$ resource ($j = 1,....8$)

$k = k^{th}$ SAR category ($k = 1,....9$)

$\alpha = \alpha^{th}$ phase of the SAR mission ($\alpha = 1,....4$)

The workload matrix W_{ik} represents the historical proportion of the time that the k^{th} SAR category occurred in conjunction with the i^{th} distance/severity region.

The performance matrix P_{kj} consists of the individual performance vectors of the j resources evaluated in all k SAR categories. Each of these performance vectors is obtained as the product of the ($\%_{k\alpha}$) matrix, the vector ϕ_{α} and a scalar which is the "probability" that the resource under consideration (j^{th}) can perform the assistance required in the k^{th} SAR category. The $\%_{k\alpha}$ matrix represents the per cent of time spent in the α^{th} phase of the k^{th} SAR category, and it is unique for each resource whose speed or response

abilities are different from any other resource. The (ϕ_α) vector represents the capability of the specific resource under consideration in the α^{th} phase of the SAR mission.

Symbolically, the relative performance (column) vector for a specific (j^{th}) resource is:

$$P_k = \left[\sum_{\alpha=1}^{3} \%_{k\alpha} \cdot \phi_\alpha + \begin{cases} \%_{k4} \cdot \phi_{A1} & \text{if } k = 1,2 \\ \%_{k4} \cdot \phi_{A2} & \text{if } k = 3 \\ \%_{k4} \cdot \phi_{A3} & \text{if } k = 4,5 \\ \%_{k4} \cdot \phi_{A4} & \text{if } k = 6 \\ \%_{k4} \cdot \phi_{A5} & \text{if } k = 7,8,9 \end{cases} \right] \cdot p(j \text{ can do } k); \quad k = 1,\ldots 9$$

The performance matrix P_{kj} is the grouping of the P_k vectors for the j resources to be evaluated. (Note: the assistance (α=4) phase of the SAR mission includes tasks that resources perform with different degrees of effectiveness, primarily dependent on the nature of the tasks. To prevent loss of information by total aggregation, this phase is divided into five sub-categories. For notation, these five sub-categories are labeled A_n (n = 1,...5). The choice of A_n depends upon the category (k) in question.)

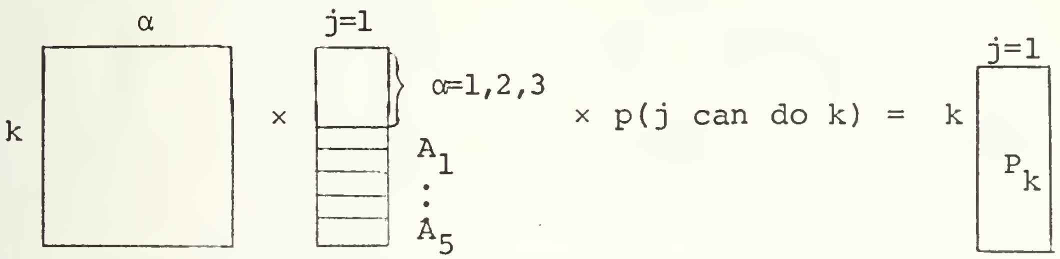
The product of the workload and performance matrices, $(W_{ik} \cdot P_{kj})$, is the measure of effectiveness in the i^{th} distance/severity region for the j^{th} resource, or:

$$MOE_{ij} = \sum_{k=1}^{9} W_{ik} \cdot P_{kj}$$

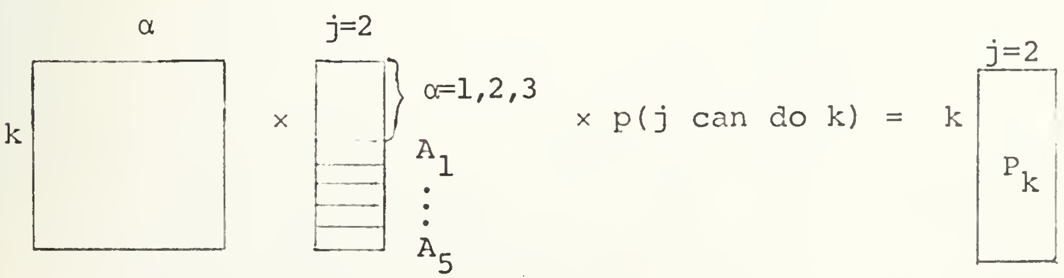
$$= \sum_{k=1}^{9} \left[\left[\sum_{\alpha=1}^{3} W_{ik} \cdot \%_{k\alpha} \cdot 0_{\alpha} + \begin{cases} \%_{k4} \cdot A1 & \text{if } k=1,2 \\ \%_{k4} \cdot A2 & \text{if } k = 3 \\ \%_{k4} \cdot A3 & \text{if } k = 4,5 \\ \%_{k4} \cdot A4 & \text{if } k = 6 \\ \%_{k4} \cdot A5 & \text{if } k = 7,8,9 \end{cases} \right] p(j \text{ can do } k) \right]$$

The model may be more easily visualized if it is shown schematically:

For resource (j=1), construct the performance vector:

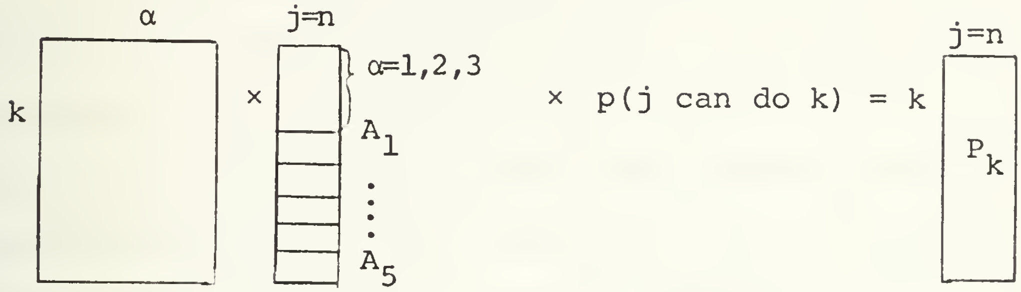


For resource (j=2), construct the performance vector:

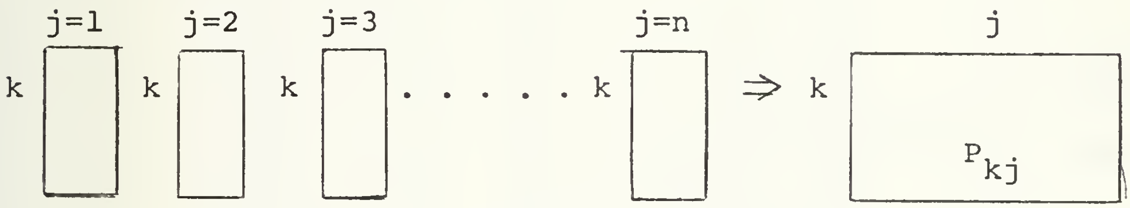


$\vdots$

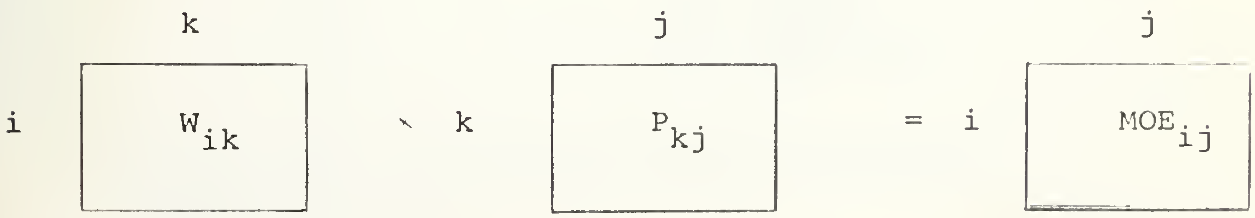
For resource (j=n), construct the performance vector:



Combine these performance (column) vectors to obtain the performance matrix (P_{kj}):



The product of the workload matrix, W_{ik}, and the performance matrix, P_{kj}, is the measure of effectiveness matrix, MOE_{ij}:



IV. MEASURE OF EFFECTIVENESS AND SUMMARY OBSERVATIONS

Detailed calculations used to arrive at the final MOE matrix are contained in Appendix II. To illustrate the operation of the analytical model the WPB 95 will be used. The scale vector (ϕ_α) and the time weighting matrix ($\%_{k\alpha}$) were derived according to sections B and C respectively. The product of these two matrices times the scalar probability of completing phase four (p_{jk}) resulted in the performance vector (P_k) as follows.

$\%_{k\alpha}$ for WPB 95

	RESPONSE	TRANSIT	SEARCH	ASSIST
a	.06	.46	.43	.05
b	.05	.42	.48	.05
c	.05	.32	.05	.58
d	.06	.66	.22	.06
e	.10	.67	.11	.12
f	.05	.63	.17	.15
g	.08	.21	.28	.43
h	.04	.25	.16	.55
i	.05	.21	.16	.58

×

		ϕ_α †
	α_1	5.0
	α_2	2.1
	α_3	2.8
α_4	A_1	6.0
α_4	A_2	10.0
α_4	A_3	6.0
α_4	A_4	5.0
α_4	A_5	10.0

$$\times\ p(x) = \begin{cases} 1 & \text{if craft can complete mission} \\ 0 & \text{otherwise} \end{cases}$$

$= P_k^{(6)}$

$P_k^{(6)}$
2.8
2.8
6.9
2.7
2.9
2.8
5.9
6.7
6.9

a. = search large object
b. = search small object
c. = tow and/or escort
d. = deliver supplies
e. = evacuate personnel
f. = comms/navigation assistance
g. = refloat
h. = dewater
i. = fight fire

† The fourth phase (α_4) consists of five sub-categories of assistance (A_1–A_5).

The performance elements for the ninety-five foot patrol boat indicate how well it can do any specific SAR mission on the arbitrary scale (0-10). There is the inherent standard of comparison incorporated into the score as mentioned earlier. The performance values were determined through a ranking process which involved collating each resource to the best performer in each phase. Thus a score of 10 is ideal and implies the best possible performance from a craft at the present state of the art in vehicle design. The underlying assumption is that the eight resources represent the most suitable vehicles for SAR on the market today. A highest score (less than 10) infers the associated craft out-performs the other resources considered and would be the logical choice based purely on its capability to respond, transit, search, and assist. The different elements of the resource's vector show relative degrees of effectiveness, dependent upon the nature of the SAR category. The most valuable contribution made by the WPB would be in towing, escorting, dewatering, and fighting fires. The effectiveness score in searching, delivering supplies, and evacuating personnel suggest areas for possible improvement.

The performance matrix is an intermediate step in determining an overall measure of effectiveness. When P_{kj} is formed by combining all P_k column vectors and then is pre-multiplied by the workload matrix, W_{ik}, a final MOE matrix is obtained.

Distance to Scene	Case Severity	a	b	c	d	e	f	g	h	i
0-3	SARSM	9.17	15.83	35.76	4.36	1.65	9.55	1.33	0.50	0.03
	SARMO	2.92	5.63	8.84	1.33	2.57	5.31	1.12	1.09	0.06
	SARSE	3.33	7.72	4.69	0.65	2.92	1.44	1.00	1.18	1.03
3-25	SARSM	38.97	66.24	120.27	11.97	4.25	19.16	1.15	1.03	0.03
	SARMO	12.94	25.59	29.33	7.75	9.85	12.79	1.86	3.51	0.18
	SARSE	22.02	46.87	15.86	6.72	14.77	4.95	1.65	2.95	1.47
> 25	SARSM	22.05	36.61	73.25	7.10	4.48	9.93	0.59	0.62	0.00
	SARMO	10.76	18.72	28.18	13.80	19.40	8.93	1.18	2.00	0.06
	SARSE	24.23	49.38	12.53	9.52	24.23	4.19	0.97	1.56	0.62

WORKLOAD MATRIX

The total performance matrix is listed below.

SAR Categories \ Resources	1	2	3	4	5	6	7	8
a	5.9	5.8	4.1	9.6	2.9	2.8	2.8	2.6
b	5.9	5.9	4.0	9.6	2.9	2.8	2.8	2.7
c	4.4	4.3	4.1	0.0	3.6	6.9	6.9	6.4
d	5.7	5.5	4.1	9.5	2.9	2.7	2.7	2.5
e	5.2	5.1	4.2	9.2	3.1	2.9	2.9	2.6
f	5.7	5.6	4.3	7.7	3.1	2.8	2.8	2.6
g	3.4	3.4	5.4	0.0	4.6	5.9	5.9	5.3
h	3.0	3.0	5.5	0.0	4.8	6.7	6.7	6.4
i	2.9	2.9	5.5	0.0	4.9	6.9	6.9	6.4

PERFORMANCE MATRIX

Resources

1. FLAGSTAFF
2. High Point
3. Voyageur
4. HH-52A
5. Hover Ferry
6. WPB 82
7. WPB 95
8. WMEC 210

SAR Categories \ Resources	1	2	3	4	5	6	7	8
SARSM	398	393	323	370	257	369	369	346
SARMO	148	146	122	159	85	125	125	116
SARSE	123	121	102	150	80	98	98	92
SARSM	1354	1337	1076	1310	856	1229	1229	1153
SARMO	542	534	433	508	336	429	429	402
SARSE	639	630	485	899	366	415	415	397
SARSM	791	781	633	748	505	733	733	687
SARMO	538	530	429	661	330	415	415	386
SARSE	705	694	523	1028	389	419	419	394
TOTAL	5238	5166	4126	5833	3204	4232	4232	3967

MOE MATRIX

The resulting matrix represents the weighted effect of the SAR distribution of cases applied to the raw performance capabilities of the resources. The individual matrix entries show the cumulative scaled value of a resource to perform all SAR related missions at a given distance offshore with varying degrees of severity. The largest row score identifies the most suitable resource available for a particular region and case severity. In examining the SARSM rows, the high speed helicopter is outscored by both hydrofoils. This points out the significance of the workload matrix. The difference in score is directly attributed to the occurrence of the large number of towing and escort cases which are usually classified as involving small danger

to property and persons. Likewise since the helicopter has zero utility in towing, its overall score is substantially reduced by the heavy percentage of towing cases in the workload matrix.

The importance of speed increases with distance offshore and case severity. The relative advantage realized by the helicopter over the Flagstaff is approximately thirty-nine per cent when the SARSM 0-3 miles offshore entries are compared to the SARSE greater than 25 miles offshore entries.

$$\left(\frac{1028 - 705}{1028}\right) - \left(\frac{370 - 398}{370}\right) = 0.39$$

By scrutinizing both the performance and the MOE matrices many discriminating observations can be made. In fact, if there were no further factors to be considered, these matrices might be used in selecting the most effective resources to fulfill mission requirements. Although this is, by itself, an unacceptable over-simplification, it may be possible to reduce the number of candidate replacement resources. These facts are apparent.

1. The larger more expensive hydrofoil offers decreased advantage in every SAR category. Purely on the basis of this MOE matrix, there is no justification for considering the High Point size hydrofoil for the SAR mission. The High Point may well have high utility under a different scenario or under a multi-mission concept. No inference is made to the contrary.

2. The Voyageur dominates the Hover Ferry in all categories. Since the two are basically equal in investment and maintenance cost the ACV should be preferred to the SES.

3. The WMEC is dominated in all categories by the WPBs. Again the WMEC may have high utility in other Coast Guard missions.

4. Resource speed dominates the performance values in the categories of search, deliver supplies, and evacuate personnel.

5. Since the WPBs are comparable in all aspects of rendering assistance, the lower personnel cost of the WPB 82 gives it a decided economical advantage.

6. The inability of the helicopter to successfully complete some SAR categories must be considered in any resource allocation scheme. Therefore there must be other capable craft operating in conjunction with the helicopter to insure coverage of all rescue situations.

The objective of reducing the number of candidate replacement resources for consideration has been achieved. Exclusion of four craft from further analysis on the basis of the MOE values does not result in any loss of information because of the dominance by a similar resource.

The potential for wide variability of assigned values for the assistance phase exists because of the subjective evaluation approach taken. For some categories, the percentage of time spent in this phase accounts for three-fourths of the total time. Consequently, the effect of increasing the scale value for assistance by one point results in a 0.75 increase in the final performance of the resource concerned. It should be realized that the new high performance craft (HPC) were not designed to perform

SAR missions while the current Coast Guard resources have been so designed. Modifications to the new HPC along the lines of Coast Guard needs most likely would result in higher performance values and a subsequent increase in the overall measure of effectiveness. For example, improved towing capability and maneuverability in a HPC could make it the most desirable SAR vehicle of the group. Generally, the structure of the model anables the analyst to easily identify the weaknesses of any resource and the significance of that weakness is emphasized by the workload distribution. This information could lead to initiation of corrective craft design or elimination of the craft from consideration because of the infeasibility of modification. In this way both the vehicle's existing capability and its potential can be recognized. For instance the Flagstaff's primary towing deficiency results from the lack of available power in the hull mode of operation. However, a change in the propulsion system might make the Flagstaff an effective, economical towing vehicle. These type investigations would necessarily have to be made before eliminating a candidate resource from consideration.

Each entry of the MOE vector for a particular resource represents the effectiveness value over all SAR categories for a particular range and case severity. Using the constant workload, with the distribution defined by the three year averages, the total MOE for all SAR categories is simply the

sum of the individual vector components. The HH-52A has the highest score; hence, it is the most effective resource in terms of time for completing the total workload. This high score was achieved despite its inability to execute the required tasks of four SAR sub-categories. The degree of effectiveness of the other resources can be compared to the HH-52A by introducing the concept of average yearly costs for each resource.

The total operating cost per year for each resource was taken from a CNA study contracted for by the Coast Guard [Ref. 3]. A life expectancy of 20 years and 1000 operating hours per year for each resource was assumed. All costs are in 1973 dollars which corresponds to the last year of the data base and are listed below.

RESOURCE	INVESTMENT COST	TOTAL OPERATING COSTS (20 YRS)	MOE VALUE	ANNUAL COST PER EFF. VALUE
FLAGSTAFF	$4,500,000	$ 4,320,000	5238	$ 84.19
HH-52A	$ 600,000	$ 7,900,000	5833	$ 72.86
VOYAGEUR	$1,500,000	$ 3,320,000	4126	$ 58.41
WPB 82'	$1,020,000	$ 1,525,000	4232	$ 30.07

The MOE values cannot be taken as absolute indications of resource worth because of the subjective assigning of scores in the assistance phase and the comparative scaling technique employed. Admittedly considerable variance in these MOE scores is possible. However, if these scores were treated as absolute values, then the following observations could be made.

When cost was introduced the WPB and the ACV yielded more effectiveness per dollar than the most effective resource (HH-52). From this it can't be concluded that the Coast Guard should exclusively go to the WPB 82 for medium range SAR coverage. There are numerous other factors involved which would have to be considered. For instance, the need for rapid response in life and death situations is obviously not provided by the WPB 82. The sea state operating restriction on the Voyageur similarly precludes considering it under any one craft concept. The helicopter can't tow and the expensive Flagstaff is only relatively effective in executing the majority of search and rescue cases. The inference is that no one resource can handle the entire workload. But since these four resources represent the best on the market some economical mix might be selected to insure compliance with statutory responsibilities. However specification of any such mix has not been the objective of this work.

V. CONCLUSIONS AND RECOMMENDATIONS

The information contained in the measure of effectiveness matrix is somewhat obscure when considered in its entirety. If considered in the whole, the column sums are a basis for comparative effectiveness. In general, total effectiveness for any resource j is:

$$\sum_{i=1}^{9} MOE_{ij}$$

The measure of effectiveness matrix may be disected in various ways to emphasize several sub-measures. Some insight into resource performance can be obtained by considering the measure of effectiveness matrix element by element. A plot of these points is helpful in visualizing any inherent relationships. Such a graph is shown (Figure 2), where i refers to the respective distance/severity region. It should be noted that there is very little difference between performance scores out to the $(i = 4)$ distance/severity zone. In considering the ranks of the resources at each distance/severity point as ordinal scale information, this difference is likewise small out to $(i = 4)$ and additionally to $(i = 5)$. The differences of performance scores and ranks of the resources is most pronounced at distance/severity levels of $(i \geq 5)$. This seems to indicate that for short distance cases (out to 3 miles) regardless of the severity and medium distance

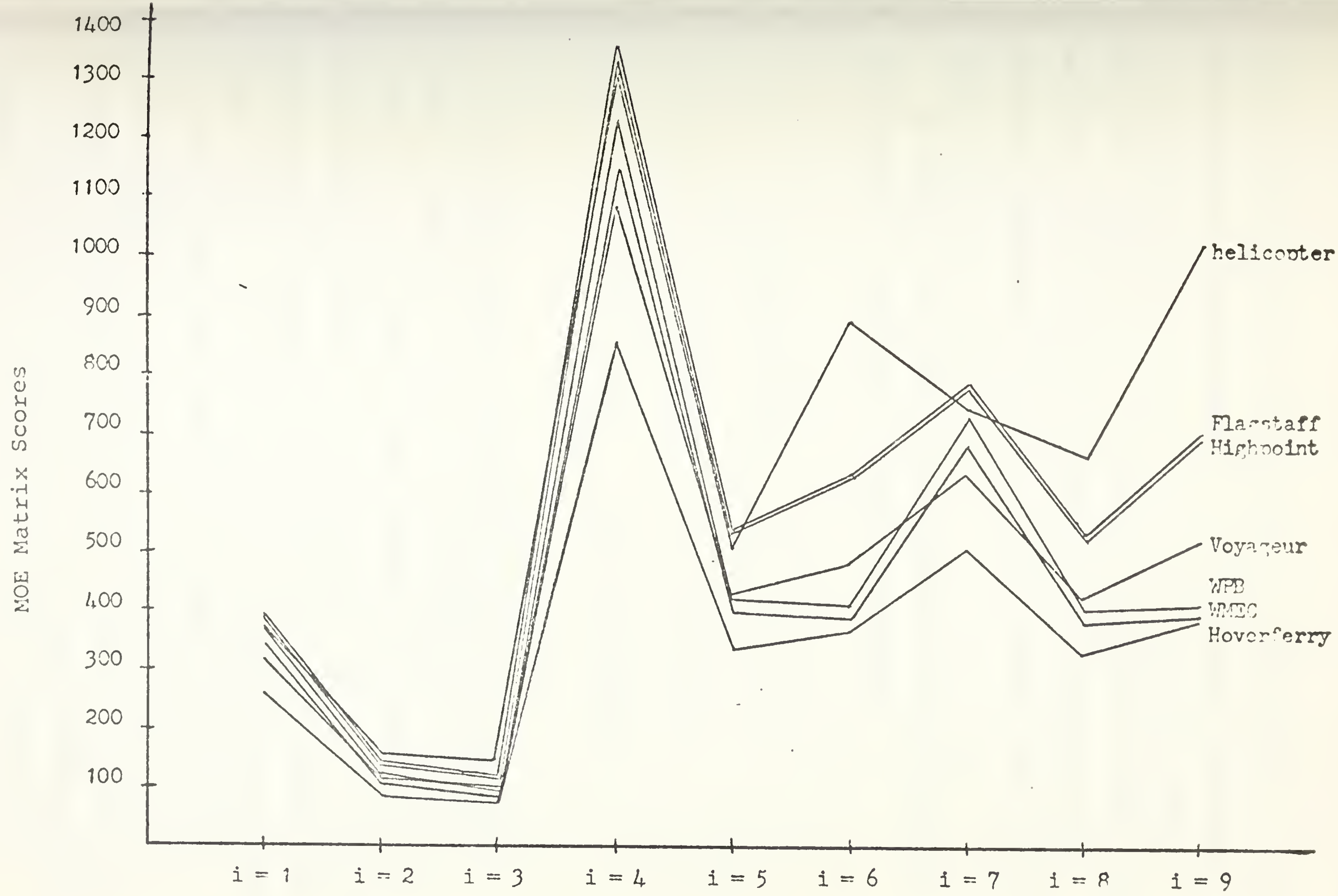


FIGURE 2. Number of Cases versus Distance Offshore/Severity
(Distance and severity increase with number.)

cases (3 to 25 miles) where severity is small there is little difference in the performance of all resources considered. At distance/severity levels of ($i \geq 5$) the graph indicates that one, or both, of the variables (distance to scene and/or severity) is causing an increase in the variability among resource performance and rank, and that perhaps the variables should be looked at separately.

In general, the total effectiveness of the j^{th} resource with respect to distance to scene is found by:

$$\sum_{i=1,2,3} MOE_{ij} \quad \text{for (0-3) miles}$$

$$\sum_{i=4,5,6} MOE_{ij} \quad \text{for (3-25) miles}$$

$$\sum_{i=7,8,9} MOE_{ij} \quad \text{for (> 25) miles}$$

As in the previous discussion, a plot of the points helps to emphasize inherent relationships and is shown (Figure 3). To make the graph clearer, only four of the resources are plotted. Of the hydrofoil craft, the Flagstaff dominated the Highpoint in all areas, so the Highpoint has been omitted. The same is true of the Voyageur with respect to the Hoverferry and the WPB with respect to the WMEC. The helicopter was obviously in a class by itself and is included. The general shape of the contours is similar to the shape of the distribution of the 25,866 actual cases in distance to scene categories and is shown at the top of page 80.

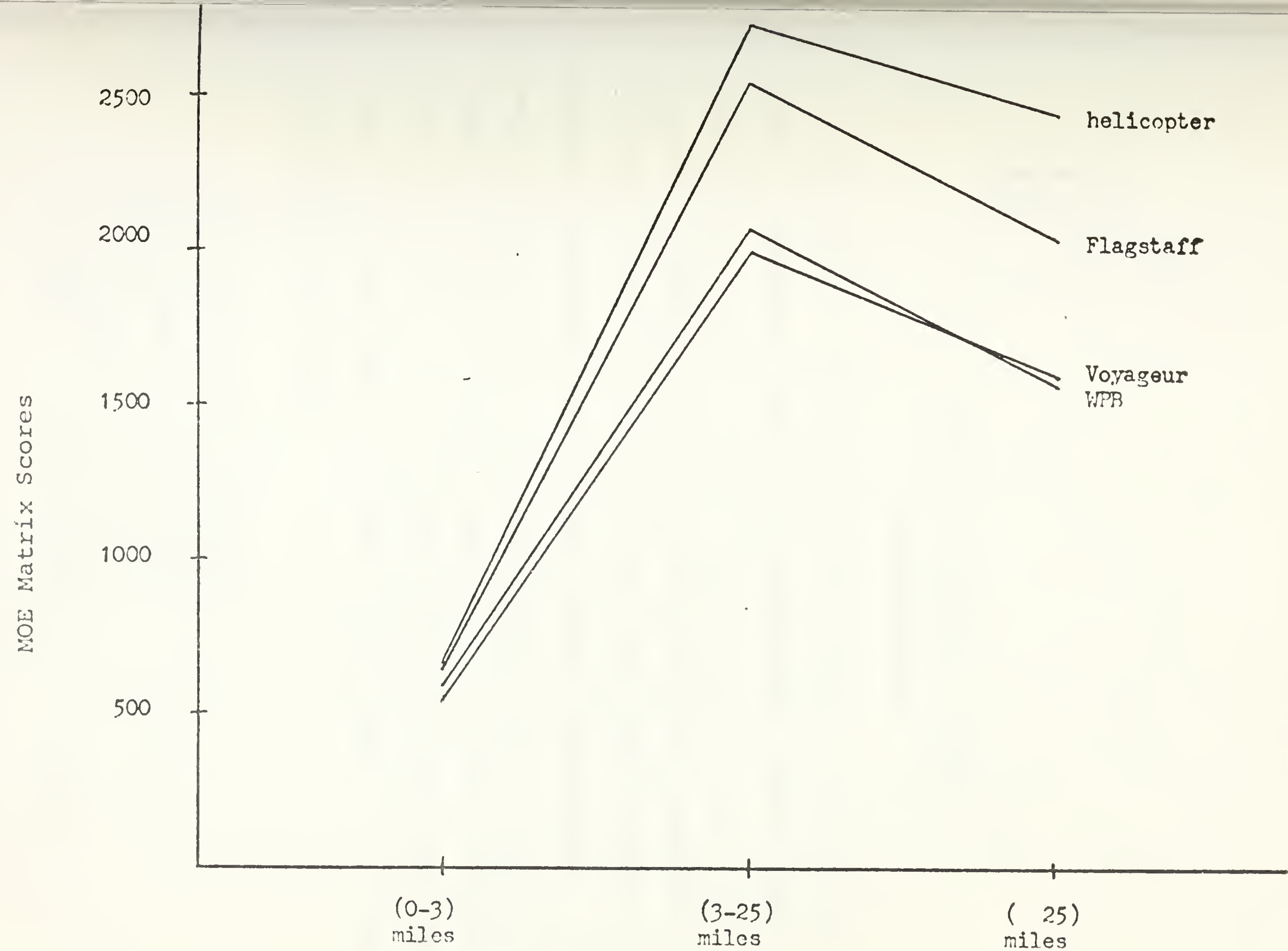
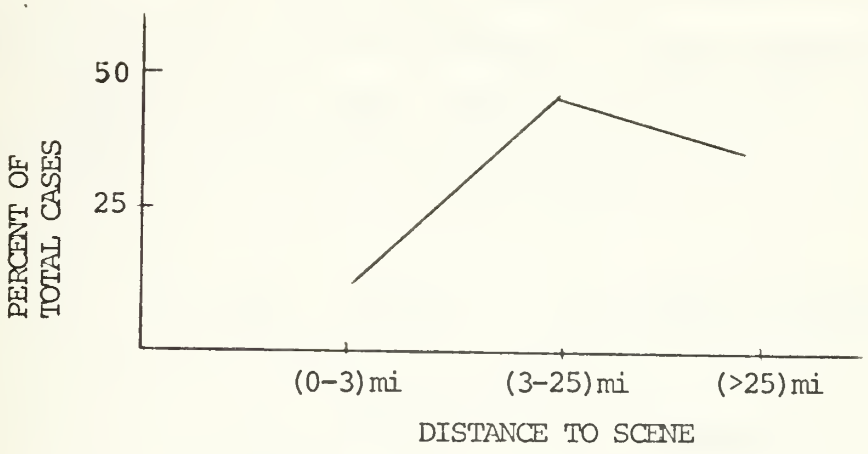


FIGURE 2. Number of Cases versus Distance Offshore



The graph of effectiveness with respect to distance to scene is somewhat revealing if viewed with resource speed considerations kept in mind. Short distance cases show little performance variability among resources explained, for the most part, by the fact that high speed capability is not fully realized over the short haul. The variance in performance in middle and long distance cases is markedly larger than short distance cases, but not greatly different from each other. Note that the rank of the performance of these four resources is the same as the ranks of the speeds included in the group:

1) Helicopter - 75 knots
2) Flagstaff - 47.4 knots
3) Voyageur - 28.4 knots
4) WPB - 15.5 knots

Consequently, and as might be expected, as distance to scene increases, high speed capability plays an increasingly important role in the performance of the resources.

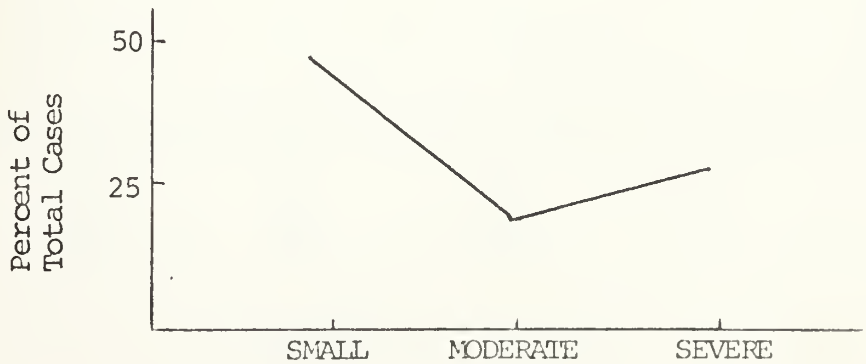
In general, the total effectiveness of the j^{th} resource with respect to severity is found by:

$$\sum_{i=1,4,7} MOE_{ij} \qquad \text{for small severity}$$

$$\sum_{i=2,5,8} MOE_{ij} \qquad \text{for moderate severity}$$

$$\sum_{i=3,6,9} MOE_{ij} \qquad \text{for great severity}$$

Again, a graph of this data is revealing and is shown (Figure 4) with the same four resources included. Also, as before, the general shape is similar to the shape of the distribution of actual cases in severity categories, shown below:



Case Severity

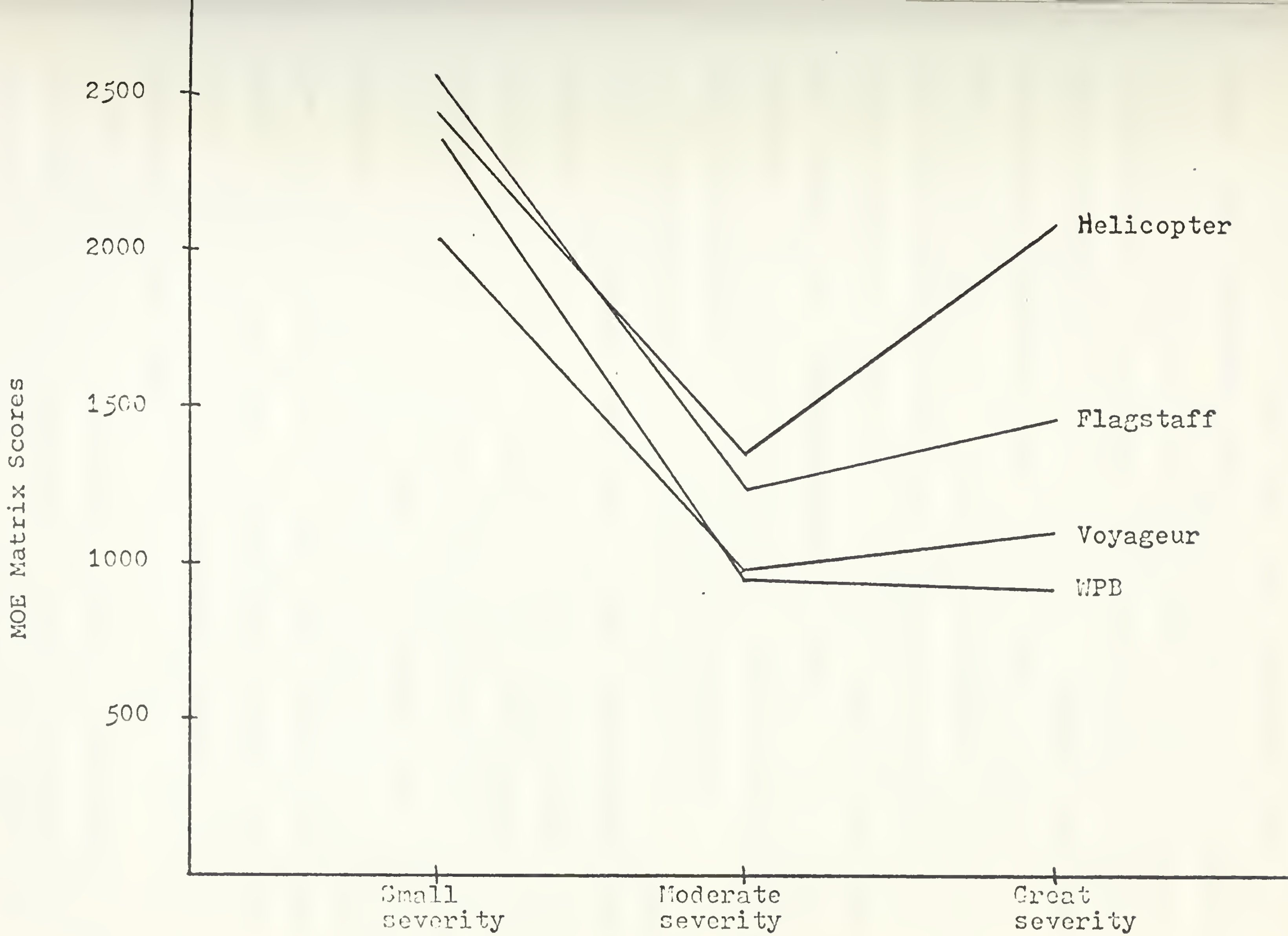


FIGURE 4. Number of Cases versus Case Severity

The graph of effectiveness with respect to severity shows that the various performance scores of all resources (except the helicopter) are relatively constant and not insignificant, brought about by a combination of differing speed capabilities and suitability for lending assistance in differing SAR categories. As for the helicopter, its high performance score in the severe category is due to the fact that since it cannot lend assistance in towing situations, and these situations are usually small or moderate in severity, the towing handicap is erased in the severe category. Consequently its relative speed advantages weigh heavily and separate it from the other resources.

It may be noted that the Voyageur ranked sixth in performance (of all seven resources) in small severity SAR, but increased its rating to fourth in great severity SAR. The explanation for this is similar to that just offered for the helicopter. Small severity cases generally involve a large proportion of the towing cases, a SAR category for which the Voyageur is not well equipped to participate in efficiently. When severity increases to a level that generally excludes routine towing operations, the Voyageur's speed capability is more fully realized and it surpasses the WPB and the WMEC for great severity SAR.

The fourth phase of the SAR mission is "assistance", and this phase is largely comprised of subjective evaluation of resource characteristics. As stated earlier, the authors'

experience in SAR and aboard three of the craft considered in this study may lend some validity to claims made, but objective data which would substantiate or refute these claims is not available. In general, assistance scores in this phase were generated from literature applicable to the craft in question and guided by operating experience. In all other major areas of this study, relationships and "weights" were formulated using actual SAR data as a base, and it is felt that these areas are as objective as possible. It is recommended that in future test and evaluation of prospective resources the Coast Guard include as an objective some comparative analysis of the operating characteristics and other notable abilities of the craft in question.

It has also become evident in working with the Search and Rescue data, that if the Coast Guard were to evaluate a new resource for the sole purpose of Search and Rescue, it may do well to limit itself to analysis of resource-types similar in ability, cost and maintainability to the 44 foot Motor Lifeboat (MLB) and smaller. For example, the SAR data shows that about one third of all sorties are handled by the 40 foot Utility boat (UTB), another 18% by the 30 foot UTB, and about 10% by the 44 foot MLB. In contrast, the WMEC handled 1.3% of all sorties, the WPB 6.2% and the helicopter about 8%. The specific hydrofoils, air cushion vehicle, and surface effect ship considered here are comparable to the WMEC, WPB and helicopter in size and potential to the Coast

Guard with respect to SAR. Due to the multi-mission capability requirements, however, these prospective resources may be desirable if, for example, the hydrofoil is intended for use in missions of Enforcement of Laws and Treaties (ELT), Marine Environmental Protection (MEP) and cooperation with the U. S. Customs Department as well as SAR.

Possible extensions of this work are numerous. Other mission areas may be examined in much the same manner as Search and Rescue has been examined here. For example, there exists data (also on magnetic tape) concerning Coast Guard response to pollution incidents and subsequent reports. In this light, an analysis of suitability of resources for MEP utilization could be attempted as an extension of this work. This methodology may be logically expanded to include several missions, as was briefly discussed in the earlier sections. A method by which combinations of resources could be studied would yield a desired characteristic to this methodology. This may involve use of the SARSIM model and is a likely extension of this study. Additionally, costs are a very large and important consideration and have been only lightly addressed here. Even in this crude treatment the WPB 82 was shown to be nearly three times more cost effective than the most effective SAR vehicle. Thorough analysis of this nature is also needed.

Finally, it is recommended that future Coast Guard test and evaluation of resources be conducted with specific

objectives outlined and required to be obtained. It is not enough to demand in a test and evaluation project "....evaluations of selected craft, operations research and mission analysis leading to the selection, design, prototype construction and evaluation of high performance watercraft to fulfill Coast Guard missions"[Ref. 5]. This leads to an aimless exercise in attempting to quantify the versatility of a resource and not a deliberate examination of resource characteristics, advantages and disadvantages. For example, the Coast Guard evaluation of the Air Cushion Vehicle and the Hydrofoil were based on those resources being placed in operational roles (actual SAR standby, Law Enforcement patrols, etc.). In a strict operational test and evaluation sense, this is not necessary. Towing ability can be judged (probably more accurately and in less time) without waiting on SAR standby for that randomly occurring towing situation. Past test and evaluation schedules show the craft in question allocated to certain mission areas on certain days. The real evaluation that appears necessary is a few steps removed from actual performance in Coast Guard missions. As pointed out in this study, SAR suitability does not have to be evaluated by operating in a SAR context. Those elements of resource capability that comprise a SAR capability can be examined separately, once they are identified. If the Coast Guard had a method of comparing resource performance and effectiveness for all missions, such as presented here for the SAR

mission, test and evaluation instructions could be explicit in defining the parameters to be observed. These parameters could then be measured accurately and in a minimum of time away from an operational role.

TYPEWRITER ALIGNMENT

RCS OSR-2000

PAGE ___ OF ___

RTMENT OF
SPORTATION
COAST GUARD
72 (Rev. 3-69)

ASSISTANCE REPORT

REPORTING UNIT	UNIT CASE OF
NAME OF DISTRESSED UNIT	
OWNER (Name, address, zip code)	

ENTIFICATION DATA

- OPFAC
- Multi-Unit Case Number
- Unit Case Number
- Month and Year Notified
- Total Number of Sorties on Case

SE DATA

- Date/Time Notified
- • Time From Occurrence to Notification
- Means of Initial CG Notification
- Nature of Distress
- Distance Offshore
- N Latitude
- W Longitude
- Method of Locating Distress
- Severity — Personnel
- Severity — Property
- Cause of Distress
- Sea State
- Wind
- Visibility

DESCRIPTION OF DISTRESSED UNIT OR UNIT ASSOCIATED WITH PERSONNEL IN DISTRESS

- Type
- Owner
- Usage
- Propulsion
- Length
- Gross Tonnage

- Off/Reg No.
- Number of Lives Lost
- Number of Lives Saved
- No. of Persons Otherwise Assisted
- 0 0 0 0 VAL-PPTY Assisted

NATURE OF DISTRESS		
SEVERITY	PERSONNEL	
	PROPERTY	

EXPLAIN "OTHER" CODES; ADD ANY CLARIFYING INFORMATION; STATE ANY UNUSUAL OCCURRENCES.

ORTIE DATA

- Type of Assisting Resource
- Assisting Resource No.
- Date/Time Underway
- Number of Resources Remaining on Stand-by
- Date/Time on Scene
- Distance to Scene or Search Area
- • Total Time on Sortie
- Assistance Rendered to Personnel
- Assistance Rendered to Property
- Performance Index — Use Comments

ORTIE DATA

- Type of Assisting Resource
- Assisting Resource No.
- Date/Time Underway
- Number of Resources Remaining on Stand-by
- Date/Time on Scene
- Distance to Scene or Search Area
- • Total Time on Sortie
- Assistance Rendered to Personnel
- Assistance Rendered to Property
- Performance Index — Use Comments

COMMAND LEVEL	INITIALS	SIGNATURE	DATE
UNIT			
GROUP			
DISTRICT			

• UNIT REPRESENTS TENTHS OF HOURS

PREVIOUS EDITIONS ARE OBSOLETE

WHITE – COMMANDANT (OSR)

APPENDIX B

VEHICLE DESCRIPTIONS AND COMPARISONS

There are numerous high performance water craft either in the production or operational stage being considered for procurement by the Coast Guard. The performance of representative models of the hydrofoil and air cushion vehicle class have been evaluated in various Coast Guard missions. The surface effect ship is one of the newest designs but has yet to be tested for mission compatibility. The SES is similar in construction to the ACV and excluding its lack of amphibious capability is comparable in all performance aspects. Any type of craft could be considered in the general decision methodology previously described. But to make the study more specific, the most likely replacement candidate for the aging WPB fleet of each class was selected for comparison with the existing conventional hull craft and the HH-52A helicopter. Each resource is described according to design characteristics and special advantages and disadvantages as they relate to SAR.

A. USS FLAGSTAFF (PGH-1)

LENGTH			74.5 feet
DRAFT	FOILS RETRACTED		4.2 feet
	FOILS EXTENDED		13.5 feet
SPEED	HULLBORNE		7 knots
	FOILBORNE	SS-0	50 knots
		SS-5	46 knots

RANGE	HULLBORNE	1560	miles
	FOILBORNE	470	miles

The Grumman built hydrofoil, FLAGSTAFF, was launched in 1969. It can operate foilborne in up to sea state five with a slight reduction in the maximum speed attained in calm seas. The Coast Guard evaluated this high performance craft's ability to satisfactorily accomplish the SAR (Search and Rescue), ELT (Enforcement of Laws and Treaties), MEP (Marine Environment Protection), and ATON (Aids to Navigation) missions for a three month period (September 1974 - December 1974). Specific observations and conclusions were made from that evaluation [Ref. 6].

a. FLAGSTAFF not equipped or designed for towing.

b. The large gap in the speed range (7-45) resulted in reduced effectiveness in some SAR operations.

c. Habitability arrangements of the vessel are below Navy minimum afloat standards.

d. One third of total operating time was recorded in the foilborne mode.

e. FLAGSTAFF was available for duty approximately eighty percent of the three month period.

f. Visual search at high speeds is difficult due to high relative wind and spray generated. Attention of lookout to actual search task was constantly diverted by the need to "hold on" in the event of a possible "crash".

g. Minimum draft requirement restricts high speed foilborne operation in shallow water. "Crashes" in water depths less than 13.5 feet would result in grounding.

h. Good foilborne stability in sea states encountered (up to 5).

i. Foilborne maneuverability is good, although the large high speed turning radius demands special pilot alertness in congested traffic.

j. Hullborne maneuverability was inadequate because of the slow engine response and lack of available thrust.

B. BELL AEROSPACE CANADA MODEL 7380 VOYAGEUR

LENGTH		65.5	feet
DRAFT		amphibious	
SPEED	SS-0	47	knots
	SS-3	20	knots
RANGE		550	miles

The Canadian Voyageur is classified as a heavy haul amphibious air cushion vehicle originally designed for transporting cargo. A smaller model ACV, the Viking was tested for adaptability to Coast Guard missions in 1971. The results of that evaluation can be generalized to the Voyageur because of the close similarity of the two models [Ref. 2].

a. Voyageur operation is absolutely limited to seas less than six feet and winds less than 30 knots.

b. The amphibious feature provides a unique accessibility capability often denied to other rescue craft because of terrain.

c. The ACV in general is inefficient and has limited maneuverability when towing a disabled boat.

d. The high noise level is fatiguing to the human and is deradating to accomplishment of tasks which require personnel communications.

e. The Voyageur has the capcity to accommodate a large number of survivors.

f. The craft is difficult to maneuver in restricted spaces whether on the cushion or in the water mode.

g. The excessive spray at slower speed impairs visual search.

h. The flexible skirt construction requires frequent replacement.

C. HM-2 HOVERFERRY

LENGTH		51	feet
DRAFT	AFLOAT	4.8	feet
	HOVERING	2.8	feet
SPEED	SS-1	35	knots
	SS-2	25	knots
	SS-3	15	knots
RANGE		160	miles

The Hovermarine Transport Limited built HM-2 [Ref. 7] has been operational in Great Britain as a profit making passenger carrying vehicle for a few years. The SES varies

from the ACV in that it has rigid sidewalls instead of the one flexible skirt. The non-amphibious HM-2, by design does not generate spray or have the noise problem associated with the ACV.

a. The submerged side keels provide excellent directional control and stability.

b. It is limited to operation in sea state three and thirty knot winds.

c. It operates efficiently throughout the entire speed range.

d. It has similar towing deficiencies as an ACV.

e. It can accommodate up to sixty passengers.

f. It has better maneuverability than the ACV at slow speeds.

g. It is easier and more economical to maintain than the ACV.

D. HH-52A "SIKORSKY SEA GUARD"

SPEED	90 knots
RANGE	150 miles offshore (allows 20 minutes on-scene loiter time)

The Sikorsky built HH-52A Sea Guard is a single engine amphibious helicopter designed primarily as a SAR vehicle. It continues to be the aviation workhorse for short range search and rescue; also, it is deployed aboard ice patrol vessels and to identify ice hazards to merchant vessel shipping lanes.

a. The Sea Guard is an efficient vehicle for delivering supplies and evacuating personnel.

b. It's range can be extended by refueling aboard surface support ships.

c. Extreme turbulence and high winds (greater than 40 knots) can limit employment of helicopters due to their inherent instability.

d. Limited capacity for survivors.

e. Unable to dewater, tow, or refloat grounded vessels without subjecting the craft to severe danger.

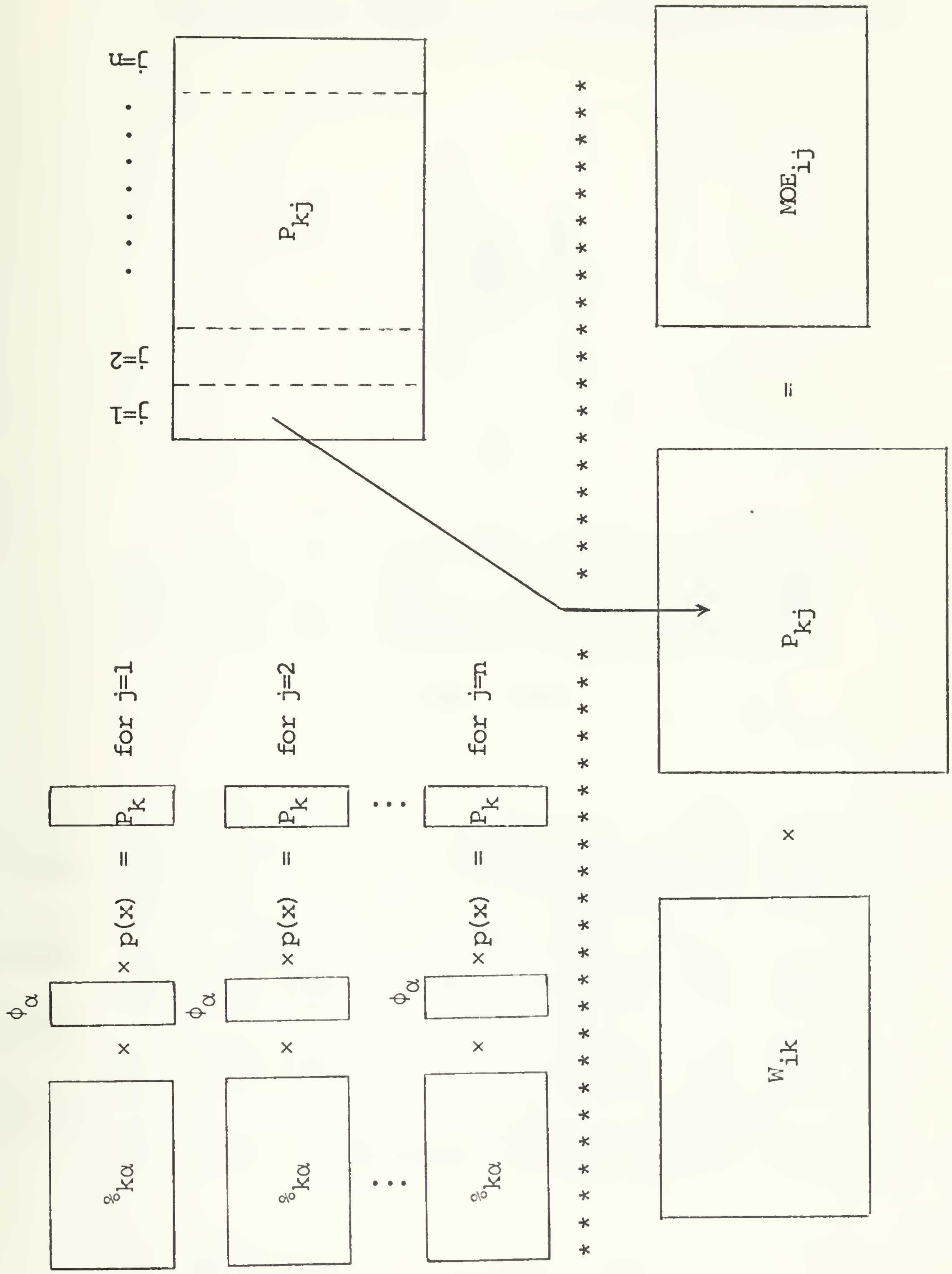
f. It is an excellent, stable search platform.

E. CONVENTIONAL HULL VESSELS

The WPB 82, WPB 95, and the WMEC 210 fall into this category. These vessels have proven to be efficient performers of SAR tasks with the primary deficiency being a lack of speed. The specifications of each vessel are listed below without any elaboration:

	WPB 82	WPB 95	WMEC 210
DRAFT	6 feet	6 feet	10 feet
SPEED	18 knots	18 knots	17.5 knots
RANGE	2000 miles	2000 miles	5000 miles

APPENDIX C. MEASURE OF EFFECTIVENESS CALCULATIONS



	Response (R)	Transit (T)	Search (S)	Assist (A)
Search, large object	.18	.37	.34	.11
Search, small object	.15	.33	.38	.14
Tow and/or escort	.09	.13	.02	.76
Deliver supplies	.18	.50	.16	.16
Evacuate personnel	.25	.44	.07	.24
Comm/Nav assistance	.12	.44	.12	.32
Refloat	.14	.10	.13	.63
Dewater	.06	.12	.07	.75
Fight fire	.09	.09	.07	.75

$\times$

	ϕ_α
R	4.0
T	6.3
S	7.1
A_1	4.0
A_2	4.0
A_3	4.0
A_4	5.0
A_5	2.0

$$\times \quad p(x) = \begin{cases} 1 & \text{if craft can complete mission} \\ 0 & \text{otherwise} \end{cases} \quad =$$

r_k
5.9
5.9
4.4
5.7
5.2
5.7
3.4
2.9

$\%_{k\alpha}$ matrix for FLAGSTAFF (j=1)

	Response (R)	Transit (T)	Search (S)	Assist (A)
Search, large object	.17	.37	.35	.11
Search, small object	.15	.34	.39	.12
Tow and/or escort	.09	.14	.02	.75
Deliver supplies	.18	.51	.16	.15
Evacuate personnel	.24	.45	.12	.31
Comm/Nav assistance	.12	.45	.12	.31
Refloat	.14	.10	.14	.62
Dewater	.06	.12	.07	.75
Fight fire	.08	.09	.07	.76

×

	ϕ_α
R	4.0
T	6.0
S	7.0
A_1	4.0
A_2	4.0
A_3	4.0
A_4	5.0
A_5	2.0

$$\times \quad p(x) = \begin{cases} 1 & \text{if craft can complete mission} \\ 0 & \text{otherwise} \end{cases} \quad =$$

Γ_k
5.8
5.9
4.3
5.5
5.1
5.6
3.4
3.0
2.9

$\%_{k\alpha}$ matrix for HIGHPOINT (j=2)

	Response (R)	Transit (T)	Search (S)	Assist (A)
Search, large object	.08	.43	.41	.08
Search, small object	.06	.39	.45	.10
Tow and/or escort	.05	.21	.03	.71
Deliver supplies	.08	.61	.20	.11
Evacuate personnel	.12	.59	.10	.19
Comm/Nav assistance	.06	.55	.15	.24
Refloat	.08	.15	.20	.57
Dewater	.04	.17	.11	.70
Fight fire	.05	.14	.11	.70

×

	ϕ_α
R	6.7
T	3.8
S	4.3
A_1	2.0
A_2	4.0
A_3	4.0
A_4	5.0
A_5	6.0

$$\times \quad p(x) = \begin{cases} 1 & \text{if craft can complete mission} \\ 0 & \text{otherwise} \end{cases} \quad =$$

Γ_k
4.1
4.0
4.1
4.1
4.2
4.3
5.4
5.5
5.5

$g_{k\alpha}$ matrix for VOYAGEUR (j=3)

	Response (R)	Transit (T)	Search (S)	Assist (A)
Search, large object	.12	.32	.36	.20
Search, small object	.10	.29	.40	.21
Tow and/or escort	.04	.08	.02	.86
Deliver supplies	.13	.45	.18	.24
Evacuate personnel	.16	.38	.07	.39
Comm/Nav assistance	.07	.35	.11	.47
Refloat	.07	.06	.10	.77
Dewater	.03	.07	.05	.85
Fight fire	.04	.05	.05	.86

×

	ϕ_α
R	10.0
T	10.0
S	10.0
A_1	8.0
A_2	0
A_3	8.0
A_4	5.0
A_5	5.0

$$\times \quad p(x) = \begin{cases} 1 & \text{if craft can complete mission} \\ 0 & \text{otherwise} \end{cases} \quad =$$

P_k
9.6
9.6
9.6
0
9.5
9.2
7.7
0
0

$g_{k\alpha}$ matrix for HH-52A HELICOPTER (j=4)

	Response (R)	Transit (T)	Search (S)	Assist (A)
Search, large object	.05	.43	.46	.06
Search, small object	.04	.42	.48	.06
Tow and/or escort	.04	.29	.05	.62
Deliver supplies	.06	.66	.21	.07
Evacuate personnel	.09	.67	.11	.13
Comm/Nav assistance	.04	.62	.17	.17
Refloat	.07	.19	.26	.48
Dewater	.03	.23	.14	.60
Fight fire	.04	.20	.15	.61

×

	ϕ_α
R	6.7
T	2.4
S	3.1
A_1	2.0
A_2	4.0
A_3	4.0
A_4	6.0
A_5	5.0

$$\times \quad p(x) = \begin{cases} 1 & \text{if craft can complete mission} \\ 0 & \text{otherwise} \end{cases} \quad =$$

r_k
2.9
2.9
3.6
2.9
3.1
3.1
4.6
4.8
4.9

$\%_{k\alpha}$ matrix for HOVERFERRY (j=5)

	Response (R)	Transit (T)	Search (S)	Assist (A)
Search, large object	.06	.46	.43	.05
Search, small object	.05	.42	.48	.05
Tow and/or escort	.05	.32	.05	.58
Deliver supplies	.06	.66	.22	.06
Evacuate personnel	.10	.67	.11	.12
Comm/Nav. assistance	.05	.63	.17	.15
Refloat	.08	.21	.28	.43
Dewater	.04	.25	.16	.55
Fight fire	.05	.21	.16	.58

×

	ϕ_α
R	5.0
T	2.1
S	2.8
A_1	6.0
A_2	10.0
A_3	6.0
A_4	5.0
A_5	10.0

$$\times \quad p(x) = \begin{cases} 1 & \text{if craft can complete mission} \\ 0 & \text{otherwise} \end{cases} \quad =$$

Γ_k
2.8
2.8
6.9
2.7
2.9
2.8
5.9
6.7
6.9

$\%_{k\alpha}$ matrix for 95 foot and 82 foot WPB (j=6)

$$
\begin{array}{l}
\\
\text{Search, large object} \\
\text{Search, small object} \\
\text{Tow and/or escort} \\
\text{Deliver supplies} \\
\text{Evacuate personnel} \\
\text{Comm/Nav assistance} \\
\text{Refloat} \\
\text{Dewater} \\
\text{Fight fire}
\end{array}
\begin{array}{cccc}
\text{Response (R)} & \text{Transit (T)} & \text{Search (S)} & \text{Assist (A)} \\
\hline
\multicolumn{1}{|c|}{.16} & \multicolumn{1}{c|}{.41} & \multicolumn{1}{c|}{.38} & \multicolumn{1}{c|}{.05} \\
\multicolumn{1}{|c|}{.14} & \multicolumn{1}{c|}{.37} & \multicolumn{1}{c|}{.43} & \multicolumn{1}{c|}{.06} \\
\multicolumn{1}{|c|}{.15} & \multicolumn{1}{c|}{.27} & \multicolumn{1}{c|}{.04} & \multicolumn{1}{c|}{.54} \\
\multicolumn{1}{|c|}{.18} & \multicolumn{1}{c|}{.57} & \multicolumn{1}{c|}{.19} & \multicolumn{1}{c|}{.06} \\
\multicolumn{1}{|c|}{.26} & \multicolumn{1}{c|}{.54} & \multicolumn{1}{c|}{.09} & \multicolumn{1}{c|}{.11} \\
\multicolumn{1}{|c|}{.14} & \multicolumn{1}{c|}{.57} & \multicolumn{1}{c|}{.15} & \multicolumn{1}{c|}{.14} \\
\multicolumn{1}{|c|}{.21} & \multicolumn{1}{c|}{.17} & \multicolumn{1}{c|}{.23} & \multicolumn{1}{c|}{.39} \\
\multicolumn{1}{|c|}{.11} & \multicolumn{1}{c|}{.22} & \multicolumn{1}{c|}{.14} & \multicolumn{1}{c|}{.53} \\
\multicolumn{1}{|c|}{.14} & \multicolumn{1}{c|}{.18} & \multicolumn{1}{c|}{.14} & \multicolumn{1}{c|}{.54} \\
\hline
\end{array}
\times
\begin{array}{c|c|}
 & \phi_\alpha \\
\hline
R & 1.7 \\
T & 2.2 \\
S & 2.9 \\
A_1 & 6.0 \\
A_2 & 10.0 \\
A_3 & 6.0 \\
A_4 & 10.0 \\
A_5 & 5.0 \\
\hline
\end{array}
\times \; p(x) = \begin{cases} 1 & \text{if craft can complete mission} \\ 0 & \text{otherwise} \end{cases}
=
\begin{array}{|c|}
\Gamma_k \\
\hline
2.6 \\
2.7 \\
7.5 \\
2.5 \\
2.6 \\
5.3 \\
6.4 \\
6.4 \\
6.4 \\
\hline
\end{array}
$$

$\%_{k\alpha}$ = matrix for 210 foot WMEC (j=7)

9.17	15.83	35.76	4.36	1.65	9.55	1.33	.50	.03
2.92	5.63	8.84	1.33	2.57	5.31	1.12	1.09	.06
3.33	7.72	4.69	.65	2.92	1.44	1.00	1.18	1.03
38.97	66.24	120.27	11.97	4.25	19.16	1.15	1.03	.03
12.94	25.59	29.33	7.75	9.85	12.79	1.86	3.51	.18
22.02	46.87	15.86	6.72	14.77	4.95	1.65	2.95	1.47
22.05	36.61	73.25	7.10	4.48	9.93	.59	.62	0
10.76	18.72	28.18	13.80	19.40	8.93	1.18	2.00	.06
24.23	49.38	12.53	9.52	24.23	4.19	.97	1.56	.62

Rows: i; columns: k

W_{ik}

5.9	5.8	4.1	9.6	2.9	2.8	2.6
5.9	5.9	4.0	9.6	2.9	2.8	2.7
4.4	4.3	4.1	0	3.6	6.9	7.5
5.7	5.5	4.1	9.5	2.9	2.7	2.5
5.2	5.1	4.2	9.2	3.1	2.9	2.6
5.7	5.6	4.3	7.7	3.1	2.9	2.6
3.4	3.4	5.4	0	4.6	5.9	5.3
2.9	3.0	5.5	0	4.8	6.7	6.4
2.9	2.9	5.5	0	4.9	6.9	6.4

Rows: k; columns: j

P_{kj}

		Flagstaff	Highpoint	Voyageur	Helicopter	Hoverferry	WPB*	WMEC
(0-3) miles	Small severity	398	393	323	370	257	369	346
	Moderate severity	148	146	122	159	85	125	116
	Great severity	123	121	102	150	80	98	92
(3-25) miles	Small severity	1354	1337	1076	1310	856	1229	1153
	Moderate severity	542	534	433	508	336	429	402
	Great severity	639	630	485	899	366	415	391
(25) miles	Small severity	791	781	633	748	505	733	687
	Moderate severity	538	530	429	661	330	415	386
	Great severity	705	694	523	1028	389	419	394

*Both WPB 82 and WPB 95 scores are the same and are included in one column

COMPUTER PROGRAM AND DOCUMENTATION

Upon the completion of every SAR incident responded to by the Coast Guard, an assistance report (CG-3272) is prepared by the assisting resource and forwarded to Coast Guard Headquarters via the chain of command. Using the Search and Rescue Reports Manual (CG-397) as reference, the assistance report provides the data base for practically all Coast Guard SAR analysis. The information on all the assistance reports submitted to Headquarters is transferred to magnetic tape annually. Any narrative or non-coded (longhand) entries are lost, but all coded information (left hand margin) is recorded.

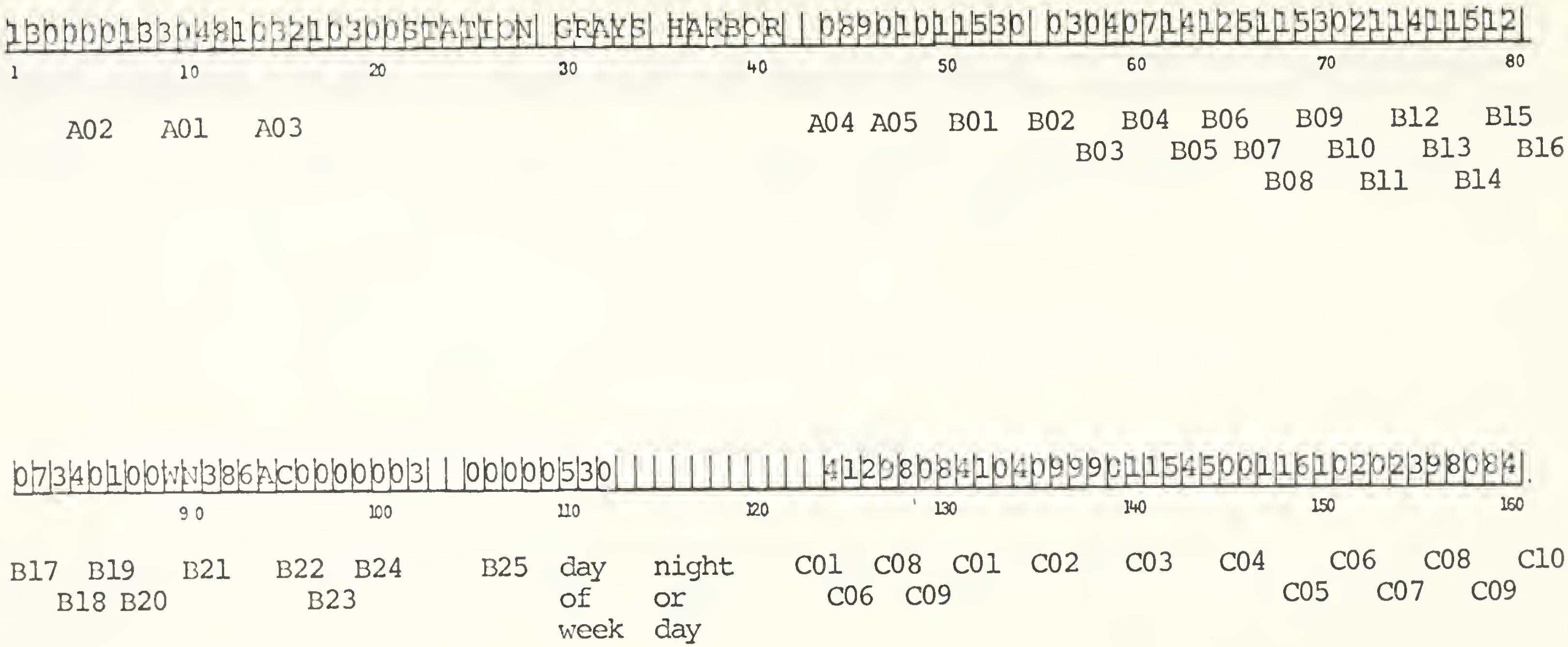
Three years of SAR data (FY71 through FY73) were available for this study, consisting of four reels of taped information. In this context, a "record" refers to the coded information from an assistance report and a "character" represents one digit of that coded data. Pertinent information concerning these tapes is shown below:

Fiscal year	local label	# of tracks	# of assist. reports	record size	block size
71	NPS351	7	73,897	160	18
72	NPS209	9	78,318	160	18
73	NPS352	7	82,980	160	18
	NPS356	7	285	160	18

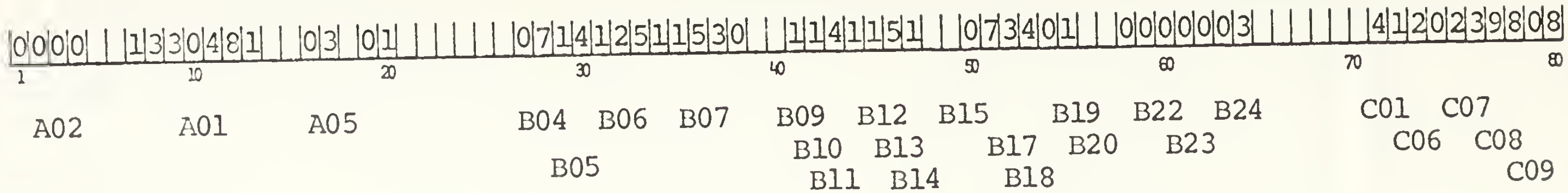
2880 characters per block

The data format for each tape was identical and is shown on page 107. Not all the data available on each case was useful for this study. Necessary information from each record was transferred to another storage device (data cell) at the NPS W. R. Church Computer Center using 80 characters per record vice 160 characters per record. Blocking the records in groups of twenty-five resulted in approximately 470 cylinders of storage on one of the Center's nine data cells. In addition to faster access to the data and quicker turn-around time, use of the data cell offered the additional advantage of storing all data in one physical memory element rather than four separate tapes. The format for the information that was transferred from the magnetic tapes to the data cell is shown on page 108.

When access to the SAR information was obtainable through use of the data cell, the FY71 to FY73 SAR history could be analyzed. A Fortran routine scanned all assistance reports (235,480 of them) and selected for further analysis those cases involving assistance rendered by either helicopter, WPB or WMEC (25,846 of them). 2069 records were lost due to incomplete or incorrect data on the assistance report itself. It is interesting to note that while it may be assumed that the helicopter, WPB and WMEC are major SAR resources, analysis shows that they are active in only 11% of the total SAR picture. CNA, studying the period from FY67 through FY69, showed that these three resource types comprised about 15% of the total. The disparity between the two figures may be



DATA TAPE FORMAT

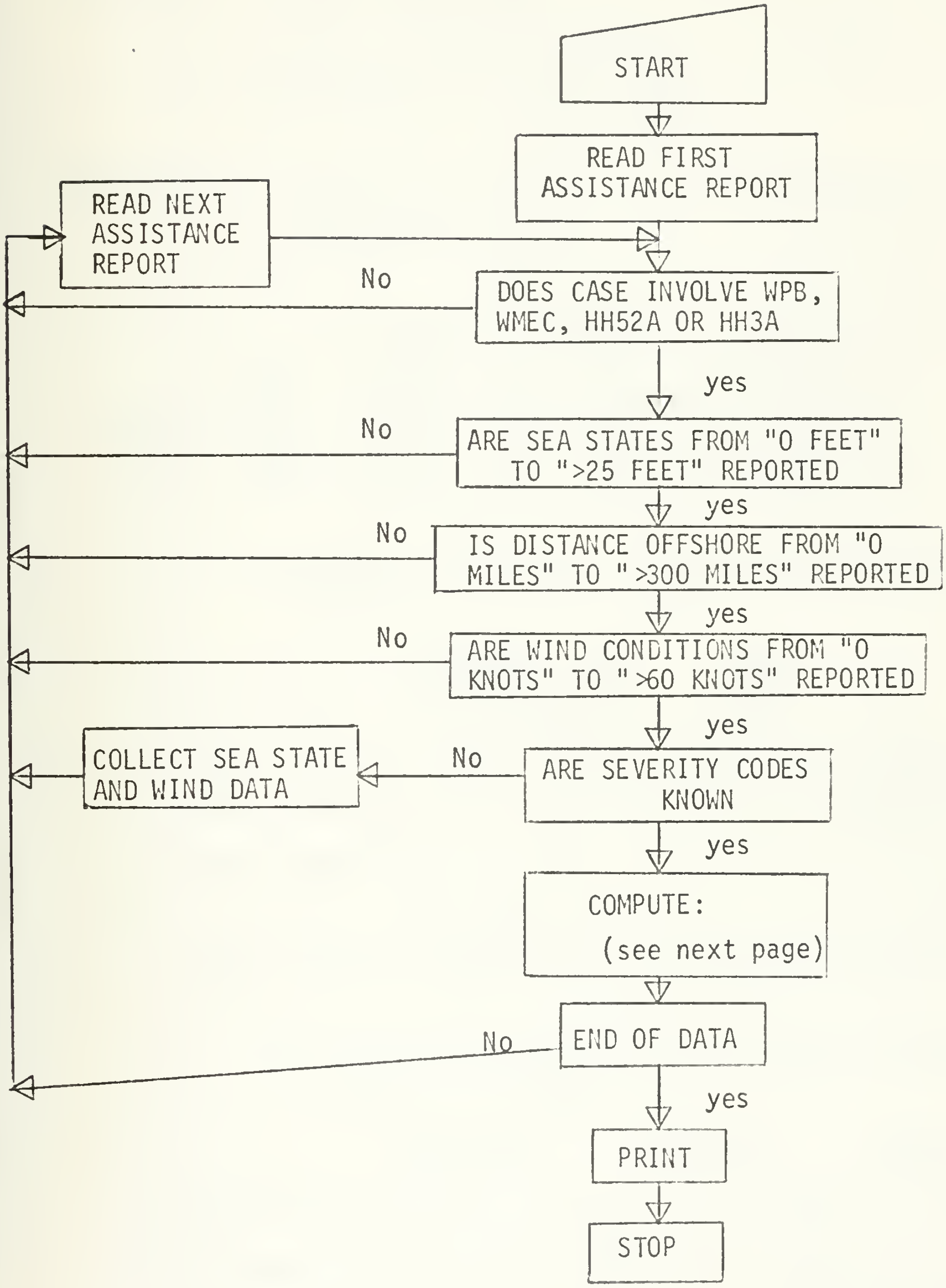


DATA CELL FORMAT

accounted for by the different time periods analyzed and different numbers of resources available. To further verify the validity of this SAR data base, forty foot and forty-four foot utility boat activity was compared to corresponding CNA figures for resource utilization. This analysis showed that 37% of all SAR involves these utility boats, and the CNA study showed the figure to be 39.5%.

The following program and chart were used to extract necessary information from the data cell containing the SAR records. The program output was integral to the formulation of the methodology presented in this study and the computer results are referred to throughout the body of this work.

FLOW CHART


START
READ FIRST ASSISTANCE REPORT
READ NEXT ASSISTANCE REPORT
DOES CASE INVOLVE WPB, WMEC, HH52A OR HH3A
No
yes
ARE SEA STATES FROM "0 FEET" TO ">25 FEET" REPORTED
No
yes
IS DISTANCE OFFSHORE FROM "0 MILES" TO ">300 MILES" REPORTED
No
yes
ARE WIND CONDITIONS FROM "0 KNOTS" TO ">60 KNOTS" REPORTED
No
yes
ARE SEVERITY CODES KNOWN
No
COLLECT SEA STATE AND WIND DATA
yes
COMPUTE:
(see next page)
END OF DATA
No
yes
PRINT
STOP

Computations:

Collect 1) sea state data

2) wind conditions data

3) distance offshore data

4) distance to scene data

Construct 1) matrix for #times cases occurred in following areas:

		severity		
		small	moderate	severe
Distance to scene	SAR1	k=1	k=2	k=3
	SAR2	k=4	k=5	k=6
	SAR3	k=7	k=8	k=9

2) matrix for #times cases occurred in following areas:

		search large	search small	tow & escort	fight fire
(k=1)	SAR1SM				
(k=2)	SAR1MO			. . . .	. . .
(k=3)	SAR1SV		. . . .		
⋮					
(k=9)	SAR3SV				

3) matrix for amount of time spent by WPB in each SAR category

	response	transit	total
search, large			
search, small			
tow & escort	. . . .		
⋮			
fight fire			

```
C*****************************************************************
C
C          PROGRAM TO EXTRACT SEARCH AND RESCUE INFORMATION
C          FROM MASTER SAR FILES (FY71 THROUGH FY73) ON CASES
C          RESPONDED TO BY WPB (95 FOOT AND 82 FOOT), WMEC,
C          AND HELICOPTER.  PARAMETERS TO BE OBSERVED ARE SEA
C          STATES, WIND CONDITIONS, DISTANCE OFFSHORE, DIST-
C          ANCE TO SCENE, SEVERITY, TYPES OF ASSISTANCE REN-
C          DERED, TIME OF NOTIFICATION, TIME UNDERWAY, TIME
C          ON SCENE, AND TOTAL TIME ON SORTIE.
C
C*****************************************************************
      DIMENSION MPORT(9,9)
      DIMENSION XTIME(9,3)
      INTEGER SS1,SS2,SS3,DOSAR1,DOSAR2,DOSAR3,DSEEN1,DSEEN2
     C,DSEEN3,SAR1SM,SAR1MO,SAR1SV,SAR2SM,SAR2MO,SAR2SV,
     CSAR3SM,SAR3MO,SAR3SV
      INTEGER A02,A01,RECODE,A05,B04,B05,B06,B07,B09,B10,B11
     CB12,B13,B14,B15,B17,B18,B19,B20,B22,B23,B24,C01,C06,
     CC07,C08,C09
      INTEGER WIND1,WIND2,WIND3
      INTEGER B01,C03,C05
      CALL ERRSET(215,260,15,1,1,218)
      NCOUNT=0
      KK=0
      KCUNT=0
      K=0
      WIND1=0
      WIND2=0
      WIND3=0
      SS1=0
      SS2=0
      SS3=0
      NDIV1=0
      NDIV2=0
      NDIV3=0
      NDIV4=0
      NDIV5=0
      NDIV6=0
      NDIV7=0
      NDIV8=0
      NDIV9=0
      DOSAR1=0
      DOSAR2=0
      DOSAR3=0
      DSEEN1=0
      DSEEN2=0
      DSEEN3=0
      SAR1SM=0
      SAR1MO=0
      SAR1SV=0
      SAR2SM=0
      SAR2MO=0
      SAR2SV=0
      SAR3SM=0
      SAR3MO=0
      SAR3SV=0
      N=0
      NX=0
      NXX=0
      NTOTAL=0
      DO 3000 J=1,9
      DO 3001 M=1,3
      XTIME(J,M)=0.0
 3001 CONTINUE
 3000 CONTINUE
      DO 1000 I=1,9
      DO 1001 J=1,9
      MPORT(I,J)=0
 1001 CONTINUE
 1000 CONTINUE
      J=0
```

```
C
C      READ PERTINENT INFORMATION FROM ASSISTANCE REPORT
C
4  READ(6,10,END=99) A02,A01,RECODE,A05,B01,B04,B05,B06,
  CB07,B09,B10,B11,B12,B13,B14,B15,B17,B18,B19,B20,B22,
  CB23,B24,C01,C06,C03,C05,C07,C08,C09
10 FORMAT(2X,I4,I7,4X,I2,27X,I2,I6,5X,I2,I1,I4,I5,1X,7I1,
  C1X,2I2,2I1,9X,2I2,I3,2IX,I2,I1,12X,I6,1X,I6,1X,I3,2I2)
   N=N+1
   IF(C01.EQ.24.OR.C01.EQ.23.OR.C01.EQ.33.OR.C01.EQ.34)
  CGO TO 11
C
C      DOES THIS CASE INVOLVE ASSISTANCE RENDERED BY
C      EITHER A WPB, WHEC, OR HELICOPTER?  IF NOT, STOP
C      AND GO TO THE NEXT CASE.
C
   GO TO 100
11 IF(B12.EQ.7.OR.B12.EQ.8.OR.B12.EQ.9) GO TO 100
C
C      IS SEA STATE DATA CORRECTLY CLASSIFIED FROM ZERO
C      TO GREATER THAN 25 FEET?  IF NOT, STOP AND GO TO
C      THE NEXT CASE.
C
   IF(B05.EQ.9) GO TO 100
C
C      IS DISTANCE OFFSHORE DATA REPORTED?  IF NOT, STOP
C      AND GO TO THE NEXT CASE.
C
   IF(B13.EQ.9) GO TO 100
C
C      IS WIND DATA RECORDED?  IF NOT, STOP AND GO TO THE
C      NEXT CASE.
C
   IF(B09.GT.B10) NSEVER=B09
   IF(B10.GE.B09) NSEVER=B10
   IF(NSEVER.EQ.0.OR.NSEVER.EQ.9) GO TO 30
C
C      IF SEVERITY CODE IS REPORTED, CONTINUE WITH ALL
C      DATA COLLECTION.  IF SEVERITY CODE IS UNKNOWN,
C      COLLECT ONLY WIND AND SEA STATE DATA, THEN GO TO
C      THE NEXT CASE.
C
   IF(B05.EQ.0.OR.B05.EQ.1) DOSAR1=DOSAR1+1
   IF(B05.EQ.2.OR.B05.EQ.3) DOSAR2=DOSAR2+1
   IF(B05.GT.3.AND.B05.LE.8) DOSAR3=DOSAR3+1
C
C      DOSAR REPRESENTS DISTANCE OFFSHORE (3 CATEGORIES)
C
   IF(C06.EQ.0.OR.C06.EQ.1) NFLAG=1
   IF(C06.EQ.2.OR.C06.EQ.3) NFLAG=2
   IF(C06.GT.3.AND.C06.LE.9) NFLAG=3
C
C      NX REPRESENTS THE NUMBER OF CASES THAT ARE UNDER
C      CONSIDERATION AT THIS POINT IN THE PROGRAM.
C
   NX=NX+1
C
C      DSEEN REPRESENTS DISTANCE TO SCENE (3 CATEGORIES)
C
   IF(NFLAG.EQ.1) GO TO 20
   GO TO 12
C
C      BLOCK TO COLLECT DATA ON DISTANCE TO SCENE AND
C      SEVERITY CODES.
C
20 DSEEN1=DSEEN1+1
   IF(NSEVER.EQ.1) SAR1SM=SAR1SM+1
   IF(NSEVER.EQ.1)K=1
   IF(NSEVER.EQ.2) SAR1MO=SAR1MO+1
   IF(NSEVER.EQ.2)K=2
   IF(NSEVER.EQ.3) SAR1SV=SAR1SV+1
   IF(NSEVER.EQ.3)K=3
```

```
      NFLAG=0
      GO TO 30
   12 IF(NFLAG.EQ.2) GO TO 21
      GO TO 13
   21 DSEEN2=DSEEN2+1
      IF(NSEVER.EQ.1) SAR2SM=SAR2SM+1
      IF(NSEVER.EQ.1)K=4
      IF(NSEVER.EQ.2) SAR2MO=SAR2MO+1
      IF(NSEVER.EQ.2)K=5
      IF(NSEVER.EQ.3) SAR2SV=SAR2SV+1
      IF(NSEVER.EQ.3)K=6
      NFLAG=0
      GO TO 30
   13 DSEEN3=DSEEN3+1
      IF(NSEVER.EQ.1) SAR3SM=SAR3SM+1
      IF(NSEVER.EQ.1)K=7
      IF(NSEVER.EQ.2) SAR3MO=SAR3MO+1
      IF(NSEVER.EQ.2)K=8
      IF(NSEVER.EQ.3) SAR3SV=SAR3SV+1
      IF(NSEVER.EQ.3)K=9
      NFLAG=0
   30 IF(B12.EQ.0.OR.B12.EQ.1) SS1=SS1+1
      IF(B12.EQ.2.OR.B12.EQ.3.OR.B12.EQ.4) SS2=SS2+1
      IF(B12.EQ.5.OR.B12.EQ.6) SS3=SS3+1
      IF(B13.EQ.0.OR.B13.EQ.1)WIND1=WIND1+1
      IF(B13.EQ.2.OR.B13.EQ.3)WIND2=WIND2+1
      IF(B13.GT.3.AND.B13.LE.8) WIND3=WIND3+1
      IF(NSEVER.EQ.0.OR.NSEVER.EQ.9) GO TO 100
C
C         NXX IS NX CASES WHERE NO SAR DATA ENTERS MATRIX
C         DUE TO THE NATURE OF THE ASSISTANCE RENDERED.
C
      IF(C08.GT.18.AND.C09.GT.36) NXX=NXX+1
      IF(C09.EQ.0.AND.C08.EQ.0) NXX=NXX+1
      J=0
C
C         BLOCK FOR SAR CATEGORY "SEARCH, LARGE OBJECT"
C         WHICH IS DEFINED AS SURFACE VESSELS GREATER THAN
C         16 FEET IN LENGTH.
C
      IF(B19.GT.1.AND.C09.EQ.1.OR.C09.EQ.2) MPORT(K,1)=
     CMPORT(K,1)+1
      IF(B19.GT.1.AND.C09.EQ.1.OR.C09.EQ.2) J=1
      IF(J.EQ.1) GO TO 19
  801 CONTINUE
C
C         BLOCK FOR SAR CATEGORY "SEARCH, SMALL OBJECT"
C         WHICH IS DEFINED AS PEOPLE OR PROPERTY THAT IS
C         LESS THAN 16 FEET IN LENGTH.
C
      IF(B19.EQ.0.OR.B19.EQ.1.AND.C09.EQ.1.OR.C09.EQ.2)MPORT
     C(K,2)=MPORT(K,2)+1
      IF(B19.EQ.0.OR.B19.EQ.1.AND.C09.EQ.1.OR.C09.EQ.2) J=2
      IF(C08.EQ.1.OR.C08.EQ.2.OR.C08.EQ.3) MPORT(K,2)=
     CMPORT(K,2)+1
      IF(C08.EQ.1.OR.C08.EQ.2.OR.C08.EQ.3)J=2
      IF(J.EQ.2) GO TO 19
  802 CONTINUE
C
C         BLOCK FOR SAR CATEGORY "TOW AND/OR ESCORT"
C
      IF(C09.GE.20.AND.C09.LE.30) MPORT(K,3)=MPORT(K,3)+1
      IF(C09.GE.20.AND.C09.LE.30) J=3
      IF(C09.EQ.32.OR.C09.EQ.33.OR.C09.EQ.36) MPORT(K,3)=
     CMPORT(K,3)+1
      IF(C09.EQ.32.OR.C09.EQ.33.OR.C09.EQ.36) J=3
      IF(C09.EQ.16) MPORT(K,3)=MPORT(K,3)+1
      IF(C09.EQ.16) J=3
      IF(J.EQ.3) GO TO 19
  803 CONTINUE
C
C         BLOCK FOR SAR CATEGORY "DELIVER SUPPLIES"
```

```
C
      IF(C08.EQ.4.OR.C08.EQ.15.OR.C08.EQ.16) MPORT(K,4)=
     CMPORT(K,4)+1
      IF(C08.EQ.4.OR.C08.EQ.15.OR.C08.EQ.16) J=4
      IF(C08.EQ.13.OR.C09.EQ.8.OR.C09.EQ.14)MPORT(K,4)=
     CMOPRT(K,4)+1
      IF(C09.EQ.15.OR.C09.EQ.24.OR.C09.EQ.25) MPORT(K,4)=
     CMPORT(K,4)+1
      IF(C09.EQ.15.OR.C09.EQ.24.OR.C09.EQ.25) J=4
      IF(C09.EQ.32) MPORT(K,4)=MPORT(K,4)+1
      IF(C09.EQ.32) J=4
      IF(J.EQ.4) GO TO 19
  804 CONTINUE
C
C         BLOCK FOR SAR CATEGORY "EVACUATE PERSONNEL"
C
      IF(C08.EQ.7.OR.C08.EQ.11.OR.C08.EQ.12) MPORT(K,5)=
     CMPORT(K,5)+1
      IF(C08.EQ.7.OR.C08.EQ.11.OR.C08.EQ.12) J=5
      IF(C08.EQ.18) MPORT(K,5)=MPORT(K,5)+1
      IF(C08.EQ.18) J=5
      IF(J.EQ.5) GO TO 19
  805 CONTINUE
C
C         BLOCK FOR SAR CATEGORY "COMMUNICATIONS AND
C         NAVIGATION ASSISTANCE"
C
      IF(C08.EQ.5.OR.C08.EQ.6.OR.C08.EQ.14) MPORT(K,6)=
     CMUPRT(K,6)+1
      IF(C08.EQ.5.OR.C08.EQ.6.OR.C08.EQ.14) J=6
      IF(C09.EQ.5.OR.C09.EQ.6.OR.C09.EQ.9) MPURT(K,6)=
     CMOPRT(K,6)+1
      IF(C09.EQ.5.OR.C09.EQ.6.OR.C09.EQ.9) J=6
      IF(J.EQ.6) GO TO 19
  806 CONTINUE
C
C         BLOCK FOR SAR CATEGORY "REFLOAT"
C
      IF(C09.EQ.13.OR.C09.EQ.23.OR.C09.EQ.33) MPORT(K,7)=
     CMPORT(K,7)+1
      IF(C09.EQ.13.OR.C09.EQ.23.OR.C09.EQ.33) J=7
      IF(J.EQ.7) GO TO 19
  807 CONTINUE
C
C         BLOCK FOR SAR CATEGORY "DEWATER"
C
      IF(C09.EQ.12.OR.C09.EQ.22.OR.C09.EQ.32) MPORT(K,8)=
     CMPORT(K,8)+1
      IF(C09.EQ.12.OR.C09.EQ.22.OR.C09.EQ.32) J=8
      IF(J.EQ.8) GO TO 19
  808 CONTINUE
C
C         BLOCK FOR SAR CATEGORY "FIGHT FIRE"
C
      IF(C09.EQ.11.OR.C09.EQ.21) MPORT(K,9)=MPORT(K,9)+1
      IF(C09.EQ.11.OR.C09.EQ.21) J=9
      IF(J.NE.9) GO TO 100
C
C         BLOCK TO CHECK TO SEE THAT ALL TIME DATA IS ENTERED
C         CORRECTLY
C
   19 IF(C03.EQ.0.OR.C05.EQ.0.OR.B01.EQ.0) GO TO 101
      IF(C03.GT.C05) GO TO 101
      IF(B01.GT.C03) GO TO 101
      NDAY=C03/10000
      NHOUR=(C03-(NDAY*10000))/100
      NMIN=(C03-(NDAY*10000))-(NHOUR*100)
      NNDAY=C05/10000
      NNHOUR=(C05-(NNDAY*10000))/100
      NNMIN=(C05-(NNDAY*10000))-(NNHOUR*100)
      NBDAY=B01/10000
      NBHOUR=(B01-(NBDAY*10000))/100
```

```
      NBMIN=(B01-(NBDAY*10000))-(NBHOUR*100)
      IF(NDAY.GT.31.OR.NNDAY.GT.31.OR.NBDAY.GT.31) GO TO 101
      IF(NHOUR.GT.23.OR.NNHOUR.GT.23.OR.NBHOUR.GT.23) GO TO
     C101
      IF(NMIN.GT.59.OR.NNMIN.GT.59.OR.NBMIN.GT.59) GO TO 101
      IF(J.EQ.1) NDIV1=NDIV1+1
      IF(J.EQ.2) NDIV2=NDIV2+1
      IF(J.EQ.3) NDIV3=NDIV3+1
      IF(J.EQ.4) NDIV4=NDIV4+1
      IF(J.EQ.5) NDIV5=NDIV5+1
      IF(J.EQ.6) NDIV6=NDIV6+1
      IF(J.EQ.7) NDIV7=NDIV7+1
      IF(J.EQ.8) NDIV8=NDIV8+1
      IF(J.EQ.9) NDIV9=NDIV9+1
C
C         KOUNT REPRESENTS THE NUMBER OF TIMES THAT ALL TIME
C         DATA WAS ENTERED CORRECTLY ON THE ASSISTANCE REPORT
C
      KOUNT=KOUNT+1
      GO TO 102
C
C         NCOUNT REPRESENTS THE NUMBER OF TIMES THAT ALL TIME
C         DATA WAS NOT ENTERED CORRECTLY ON THE ASSISTANCE
C         REPORT
C
  101 NCOUNT=NCOUNT+1
      GO TO 103
  102 CONTINUE
C
C         BLOCK TO COMPUTE RESPONSE TIME AS THE DIFFERENCE
C         BETWEEN THE TIME UNDERWAY AND TIME NOTIFIED
C
      IF(NMIN.LT.NBMIN) GO TO 9000
      GO TO 9001
 9000 NMIN=NMIN+60
      NHOUR=NHOUR-1
      IF(NHOUR.EQ.-1) KK=5
      IF(KK.EQ.5) NHOUR=23
      IF(KK.EQ.5) NDAY=NDAY-1
      KK=0
 9001 RMIN=NMIN-NBMIN
      IF(NHOUR.LT.NBHOUR) GO TO 9002
      GO TO 9003
 9002 NHOUR=NHOUR+24
      NDAY=NDAY-1
 9003 RHOUR=NHOUR-NBHOUR
      RDAY=NDAY-NBDAY
      RESPON=(RDAY*24)+RHOUR+(RMIN/60.)
      IF(RESPON.GT.1.5) GO TO 101
      IF(NNMIN.LT.NMIN) GO TO 6000
      GO TO 6001
C
C         BLOCK TO COMPUTE TRANSIT TIME AS THE DIFFERENCE
C         BETWEEN TIME ON SCENE AND TIME UNDERWAY
C
 6000 NNMIN=NNMIN+60
      NNHOUR=NNHOUR-1
      IF(NNHOUR.EQ.-1) KK=4
      IF(KK.EQ.4) NNHOUR=23
      IF(KK.EQ.4) NNDAY=NNDAY-1
      KK=0
 6001 TMIN=NNMIN-NMIN
      IF(NNHOUR.LT.NHOUR) GO TO 6002
      GO TO 6003
 6002 NNHOUR=NNHOUR+24
      NNDAY=NNDAY-1
 6003 THOUR=NNHOUR-NHOUR
      TDAY=NNDAY-NDAY
      TOTAL=(C07/10)+RESPON
      TRANS=(TDAY*24)+THOUR+(TMIN/60.)
      IF(TRANS.GE.TOTAL) GO TO 103
      XTIME(J,1)=XTIME(J,1)+RESPON
```

```
      XTIME(J,2)=XTIME(J,2)+TRANS
      XTIME(J,3)=XTIME(J,3)+TOTAL
103   IF(J.EQ.1) GO TO 801
      IF(J.EQ.2) GO TO 802
      IF(J.EQ.3) GO TO 803
      IF(J.EQ.4) GO TO 804
      IF(J.EQ.5) GO TO 805
      IF(J.EQ.6) GO TO 806
      IF(J.EQ.7) GO TO 807
      IF(J.EQ.8) GO TO 808
      IF(J.EQ.9) GO TO 100
100   GO TO 4
 99   WRITE(6,700) SS1,SS2,SS3
 700  FORMAT(1X,'SEA STATE TOTALS ARE',2X,3I8)
      WRITE(6,709) WIND1,WIND2,WIND3
709   FORMAT(1X,'WIND CONDITICNS TOTALS ARE',3I8)
      WRITE(6,701) DOSAR1,DOSAR2,DOSAR3
 701  FORMAT(1X,'DISTANCE OFFSHORE TOTALS ARE',2X,3I8)
      WRITE(6,702) DSEEN1,DSEEN2,DSEEN3
 702  FORMAT(1X,'DISTANCE TO SCENE TOTALS ARE',2X,3I8)
      WRITE(6,703) SAR1SM,SAR1MO,SAR1SV
 703  FORMAT(1X,3I10)
      WRITE(6,703) SAR2SM,SAR2MO,SAR2SV
      WRITE(6,703) SAR3SM,SAR3MO,SAR3SV
      DO 800 K=1,9
      WRITE(6,706) (MPORT(K,L),L=1,9)
 706  FORMAT(1X,9I8)
 800  CONTINUE
      WRITE (6,707) NX,NXX,N
 707  FORMAT(1X,'NX  ',I8,'NXX  ',I8,'N  ',I8)
      DO 40 I=1,9
      DO 41 J=1,9
      NTOTAL=NTOTAL+MPORT(I,J)
  41  CONTINUE
  40  CONTINUE
      WRITE(6,708) NTOTAL
 708  FORMAT(1X,'TOTAL OF MATRIX ENTRIES IS',2X,I10)
      DO 6004 J=1,9
      WRITE(6,6005) (XTIME(J,L),L=1,3)
6005  FORMAT(1X,3F15.3)
6004  CONTINUE
      WRITE(6,6006) KOUNT,NCOUNT
6006  FORMAT(1X,2I10)
      WRITE(6,9009) NDIV1,NDIV2,NDIV3,NDIV4,NDIV5,NDIV6,
     CNDIV7,NDIV8,NDIV9
9009  FORMAT(1X,9I10)
      STOP
      END
```

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